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FIRST DIAGNOSTIC TESTS OF A 75MM SOLID-FUEL RAMJET TUBULAR PROJECTILE

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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
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A series of six prototype 75mm solid-fuel ramjet tubular (SFRJ) projectiles were tested at the Ballistic Research Laboratories Transonic Range Facility during June 1982. The purpose of the tests was to evaluate the performance of the SFRJ projectile with a new cowl configuration and with various size nozzles and inlet steps. The firings were instrumented with cameras and a Hawk radar to provide information on structural integrity, sabot performance, flight stability,

fuel ignition, and drag. All rounds were fired at velocities near 1,500 m/s and good radar data were obtained. Although some yaw was visually observed on all flights, no instabilities were detected. One round experienced structural failure. Four rounds demonstrated successful autoignition with burn times in the order of two seconds. Finally, one round experienced a long burn time of about eight seconds, an anomalous performance. Further tests are planned to determine aerodynamic coefficients, fuel performance parameters, and consistency of burn time.

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I. INTRODUCTION

A program to develop a solid-fuel, tubular projectile as a training munition for anti-armor devices such as the M735 APFSDS weapon has been underway at the Ballistic Research Laboratory, ARRADCOM in conjunction with the work of the Aerodynamics Research and Concepts Section of the Chemical Systems Laboratory, ARRADCOM, and contractual work by the Chemical Systems Division of the United Technologies Corporation. The goal of the program is the demonstration of a training vehicle capable of low dispersion at a three-kilometer target with a safety range of less than eight kilometers.

The United Technologies contract produced the design of a 75mm prototype vehicle consisting of a tubular solid-fuel ramjet with an inlet through which ram air passes in flight. A fuel grain lines the interior walls of the tubular vehicle forming a combustion chamber. A nozzle is included at the interior rear of the projectile to accelerate the combustion gases and produce thrust. The ramjet tubular projectile was designed to achieve autoignition at speeds above Mach 4 and to develop thrust for about the first two or three seconds of flight.

Initial and demonstration test firings of the 75mm prototype SFRJ were conducted at the BRL Transonic Range Facility during 1981.[1,2] The initial firings were done to demonstrate structural integrity and autoignition. None of the initial four rounds fired in 1981 achieved the full spin rate needed for a gyroscopically stable flight. After some projectile and sabot modifications, a demonstration test program of six projectiles was conducted in the summer of 1981. These modifications, consisting of interconnecting the sabot and the projectile and pinning the nozzle to the projectile body, produced flights which demonstrated flight stability and autoignition. The burn times for these demonstration projectiles were somewhat shorter than desired. As a result, a diagnostic test program was designed to determine the effects of various projectile parameters such as cowl design, type of fuel, nozzle and inlet dimensions, on the flight performance.

During June of 1982, the first six rounds of the diagnostic program were tested at the Transonic Range. These projectiles all used the same fuel, had reduced weight, and a new inlet cowl design but differed in nozzle and injector diameters. The rounds were all launched at a muzzle velocity near 1,500 meters/second and Hawk radar tracking data were obtained on all flights. Unlike previous tests, no dummy round was fired for drag comparison purposes. This report presents the results of the first diagnostic series test firings.

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1. *D. Olson and W. H. Mermagen, "Initial Test Firings of a Solid Fuel Ramjet Tubular Projectile," ARBRL-MR-03212, November 1982 AD B069824L*

2. *W. H. Mermagen and D. Olson, "Demonstration Test Firings of a Solid Fuel Ramjet Tubular Projectile," ARBRL-MR-03213, November 1982 AD B069823L*

II. DESCRIPTION OF TEST PROGRAM

The structural design of the prototype projectiles was not changed from previous designs. The 75mm test projectiles were made to be compatible with a modified version of the M392 sabot. A new, low-drag cowl design was incorporated into the test vehicle. The weight was substantially reduced from a nominal 3.6 kg to 3.0 kg. Figure 1 shows the design of the projectile and contains values for two injector diameters and three throat diameters. Thus, a total of six different configuration projectiles was fabricated. The physical characteristics of the test rounds are listed in Table 1.

TABLE 1. PHYSICAL CHARACTERISTICS OF SFRJ TEST ROUNDS

Round	Nozzle Throat (cm)	Projectile Weight (kg)	Propellant Weight (kg)	I_x ($kg\text{-}cm^2$)	I_y ($kg\text{-}cm^2$)	C.G. (from rear end (cm)
21170	3.59	2.71	.292	31.3*	273.5*	13.2
21171	3.86	2.68	.297	31.3*	273.5*	13.2
21172	4.09	2.66	.292	31.3*	273.5*	13.3
21173	3.59	2.71	.293	31.3*	273.5*	13.3
21174	3.86	2.71	.294	31.3*	273.5*	13.5
21175	4.09	2.68	.292	31.3*	273.5*	13.6

* Average value for six rounds.

The M68 105mm tank cannon was set up in a self-propelled mount and oriented to fire over the yaw-card range at an elevation of 12 degrees and an azimuth of 206 degrees 47 minutes from true North. Test support instrumentation consisted of a Hawk doppler velocimeter, one smear camera, and two framing cameras. The smear camera was located 39.37 metres from the muzzle along the line of fire and was used to confirm autoignition and structural integrity. The framing cameras were located as shown in the test layout of Figure 2. The framing cameras were used to confirm the continuous burning of the propellant and to provide pictorial evidence of flight stability. The Hawk radar was located 26.11 metres behind the weapon, on the line of fire and provided velocity-time histories for each round.

III. DATA ANALYSIS

The primary data-gathering device for these tests was the Hawk doppler velocimeter. The output of the Hawk is the radar doppler return which is recorded on magnetic tape. The doppler return is processed through tracking filters using a calibration factor for the particular radar to give velocity versus time histories. For these tests, the doppler return was analyzed at approximately 5 ms intervals. Radar data processing was accomplished using waveform analysis equipment provided by the Interior Ballistics Division, BRL.[3] The velocity-time data for each firing was then further analyzed using the method of Chapman and Kirk[4] to obtain fitted velocity and drag coefficients.

The drag equation, in scalar form, is given as

$$m \dot{V} = -D = -\frac{1}{2} \rho V^2 S C_D \tag{1}$$

where m is the mass of the projectile, V the velocity along the trajectory, ρ is the air density, S is a reference area, and C_D is the drag coefficient. The reference area for the ramjet projectile was based on the nominal diameter of 75mm. The method of Chapman/Kirk uses a numerical integration scheme to perform a nonlinear least squares fit of the above equation to the velocity data. The parameters of the fit are the velocity and the drag coefficient. A linear variation of mass with time was assumed. Meteorological data were obtained by direct measurement of atmospheric conditions using a Rawinsonde met device. A nominal trajectory was computed using a six-degree-of-freedom code to provide position-time information for the reduction. The final result of the fitting process was total drag coefficient and velocity along the trajectory as a function of time.

The Hawk radar provides velocity-time data (after processing) in the form of radial velocity or velocity along the line of sight of the radar. In order to obtain a fit of drag coefficient from the data, the information must first be rectified so that the velocity along the trajectory is considered for the Chapman/Kirk reduction. This was done by performing a six-degree-of-freedom calculation for a nominal trajectory and then projecting the observed radial velocities onto the local tangent to the trajectory. After a single reduction, the derived values of drag coefficient were used in the six-degree-of-freedom code and the process was iterated to produce a new trajectory with new tangents. Only a single iteration of this process was used.

The drag coefficient is usually considered to be a measure of retardation, so that positive values of C_D in Equation (1) mean that the projectile will lose velocity. Since there is no independent method for measuring ramjet thrust, C_D obtained from the fitting process is interpreted to be a measure of the total force acting on the projectile, to include retardation and thrust.

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3. *J. N. Walbert, "Application of Digital Filters and the Fourier Transform to the Analysis of Ballistic Data," BRL Technical Report ARBRL-TR-02347, July 1981 (AD A102890).*

4. *R. H. Whyte and W. H. Mermagen, "A Method for Obtaining Aerodynamic Coefficients From Yawsonde and Radar Data," Journal of Spacecraft and Rockets, Vol. 10, No. 6, June 1973, pp. 384-388.*

Thus, should C_D turn out to be a negative quantity, then the thrust may be considered greater than the retardation. In previous tests, thrust was calculated from the difference in drag between the live SFRJ vehicle and an inert projectile as follows:

$$\text{Thrust} = \frac{1}{2} \rho V^2 S \Delta C_D \tag{2}$$

where delta C_D is the difference in drag coefficient between the live SFRJ and an inert SFRJ at the same Mach number. The tests described here did not include an inert SFRJ. As a result, an estimate of the inert drag coefficient was made from an extrapolation of the supersonic inert drag curve formed by the post burnout measurements averaged from all data rounds.

IV. FIRING RESULTS

Six SFRJ projectiles were fired on 16 June 1982 at the BRL Transonic Range area. All projectiles, except for one, retained structural integrity. Autoignition occurred for all rounds before 39.37 metres from the muzzle, as evidenced by smear camera records. Burning times observed in flight varied from 1.8 to 7.7 seconds. Good camera data were obtained on all flights and presented in Figures 3 - 10. Radar tracks were obtained on all flights with tracking times from about three to more than 10 seconds. Early radar acquisitions provided useful high Mach number information.

Since there were round-to-round differences in nozzle throat diameter and injector step diameter, the performance of each round will be discussed separately. The rounds are presented in the order fired. A summary of the firing results is presented in Table 2.

TABLE 2. SUMMARY OF FIRING RESULTS

Round	Injector Diameter (cm)	Nozzle Throat Diameter (cm)	Muzzle Velocity (m/sec)	Radar Track (sec)	Burn-out (sec)	Remarks
21170	4.31	3.59	1450	4.1	2.4	Normal burning
21171	4.31	3.86	1460	2.8	---	Broke up at rear end
21172	4.31	4.09	1478	8.1	1.8	Radar antenna changed to 186 mills
21173	3.68	3.59	1455	9.4	7.7	Long burn
21174	3.68	3.86	1463	10.6	2.8	Normal burn
21175	3.68	4.09	1504	10.4	2.0	Normal burn

Round 21170. Round 21170 had the smallest nozzle throat and the larger of the injector diameters. This was the first round fired and the smear camera showed normal autoignition (Figure 3). The flight was stable during the burning process, although some yawing motion was observed visually and corroborated from the corkscrewing of the exhaust plume. The radar velocity time data are shown in Figure 11 and are not corrected for trajectory curvature. A short radar track was due to the fact that this was the first burning projectile available for the radar. Prior tests have shown that the ability to track projectiles is a function of the experience of the radar operator with that particular shell. Figure 12 shows the result of a 6-DOF computation for velocity using fitted drag coefficient values. The computed results are compared to the radar-determined velocity, corrected for trajectory curvature.

The reduced drag coefficient is shown as a function of time of flight in Figure 13 and as a function of range in Figure 14. The distance downrange was computed from the 6-DOF program. Clearly, the burn time was insufficient to allow powered flight to three kilometers. A plot of C_D versus Mach number is shown in Figure 15. The data are compared to a reference drag profile shown as the dashed line. Between Mach 1 and Mach 3.3, the reference drag profile was obtained from the average drag of rounds 21172, 21174, and 21175 after burnout. The reference drag between Mach 3.3 and Mach 5.0 is estimated and not based on experimental results.

Using the reference drag profile and the measured C_D for this round, a plot of thrust versus time of flight was constructed and is shown in Figure 16. The thrust level of 200 lb during burning is about the same as the thrust computed during the demonstration tests of 1981.

Round 21171. Round 21171 had an intermediate throat diameter and a large injector diameter. Unfortunately, this projectile experienced structural failure at launch, as is seen in Figure 4. From the smear photograph one can readily see that the nozzle insert has separated from the remainder of the projectile. This mechanical failure was probably due to ill-fitting pins used to hold the assembly together. Because of the structural failure, no further reduction was performed, even though radar data exist for the first three seconds of flight.

Round 21172. Round 21172 had the largest nozzle throat diameter and the larger injector diameter. Closed-pipe tests indicated that this projectile should experience the shortest burn time. A change in radar antenna elevation was made at this time, and a longer tracking time was achieved than for the two previous rounds fired. This increased tracking ability persisted for the remainder of the test program. The smear photograph taken at 39.37 metres from the muzzle showed that autoignition had been achieved, see Figure 5. Experienced observers reported that the flight was stable although a small yawing motion was detected and corroborated by the corkscrew pattern of the exhaust plume.

The radar velocity-time data, not corrected for trajectory curvature, are shown in Figure 17. The raw data show a burn time of about 1.8 seconds, the shortest burn experienced in the test. Figure 18 shows the results of the 6-DOF computation in comparison to the radar data corrected for trajectory curvature. The excellent agreement is undoubtedly due to the fact that the drag coefficient used in the 6-DOF was obtained from the radar data. This drag coefficient is shown as a function of time in Figure 19 and as a function of range in Figure 20. Because of the long radar track time, it is possible to see the transonic drag of the vehicle. The inlet cowl elliptical design produced a significant reduction in drag after burnout, a reduction of about 40% compared to earlier projectiles with conical cowls. Nevertheless, the shorter burn time gave a powered flight to only two kilometers.

Figure 21 compares the C_D-Mach number history of round 21172 to the reference drag profile. A thrust versus time was computed from the difference between these two curves and is shown in Figure 22. A somewhat higher thrust, initially about 250 lb, was observed than for the projectile with the smallest throat and the same injector diameter. Based on closed-pipe tests, this result is expected. Except for cowl shape and flight weight, round 21172 had the same configuration as round 19366 fired in June of 1981. The maximum thrust for round 19366 was about 240 lb at launch.

Round 21173. Round 21173 used the smallest nozzle throat diameter and had the smaller injector diameter. Although this configuration should produce the longest burn time, the length of burn actually observed was completely unexpected. Figure 23 shows the raw radar velocity-time history for this flight. A close examination of the velocity slope shows that burnout occurred at about 7.7 seconds. Figure 5 shows the smear camera photograph of the burning at 39.37 metres from the muzzle. The burning appears to be normal and similar to the other SFRJ vehicles tested except that the diameter of the plume seems somewhat smaller. Visually, this round also appeared to have some small yaw with the characteristic corkscrew plume. Further visual observations confirmed the long duration of the plume, one observer reporting about 7-8 seconds of burn.

A comparison between a 6-DOF velocity computation using the reduced drag values for this round and the radar data corrected for trajectory curvature is shown in Figure 24. The reduced C_D for this round is shown in Figure 25 as a function of time and in Figure 26 as a function of range. Although the drag during thrust for round 21173 was about 50% higher than for the other rounds fired during this program, the persistent low C_D values for the first four seconds of flight seem to suggest that more energy was derived from the fuel during the burn. Figure 27 shows the drag versus Mach number in comparison to the reference drag while Figure 28 gives the resultant thrust versus time. If the thrust-time curve is integrated during the burn to obtain total energy for round 21173 and compared with similar calculations for rounds 21174 and 21175 one finds that the total energy (area under the curve) for 21173 is almost double that for 21174 or 21175.

Round 21174. Round 21174 had an intermediate throat diameter and the smaller injector diameter. A long burn time was expected and 2.8 seconds of burn were achieved. Figure 7 shows the smear camera photograph of the projectile in flight. The plume seems somewhat narrower or of smaller diameter than for the other projectiles tested with the exception of 21173. The radar was able to track this flight for about 10.6 seconds with the resultant uncorrected velocity profile shown in Figure 29. Observers reported a stable flight with a small amount of yaw evidenced by the corkscrew plume.

Figure 30 compares the corrected-for-curvature radar velocity profile with a 6-DOF profile based on fitted values of drag coefficient. Figure 31 shows C_D versus time and Figure 32 shows C_D versus range, the result of the Chapman/Kirk fitting of the drag equation to the velocity data. As seen from the figures, the projectile sustained powered flight to well past three kilometers. The transonic drag behavior is also well determined from these data. Figure 33 shows the drag coefficient as a function of Mach number in comparison with the reference drag profile.

Thrust versus time is plotted for round 21174 in Figure 34. Almost constant thrust is sustained for the first 2.5 seconds of flight and the level of thrust, about 200 lb, compares to the thrusts experienced in the demonstration test firings of 1981.

Round 21175. This round had the largest nozzle diameter with the smaller injector diameter and a short burn time was anticipated. A normal burn, about two seconds in duration, is seen in the smear camera photograph of Figure 8. Some small yaw was visually observed and verified by the corkscrewing of the rocket plume. The flight was observed to be stable. A radar track of approximately 10.4 seconds duration produced the uncorrected velocity-time history shown in Figure 35. The corrected radar velocity is compared to a 6-DOF computation in Figure 36.

The reduced drag coefficient is plotted against time in Figure 37 and against range in Figure 38. From these plots, it is seen that powered flight stopped before three kilometers of range. In Figure 39 the drag coefficient is shown as a function of Mach number and compared to the reference drag profile. From these results, a thrust curve was computed and is shown in Figure 40. The thrust is slightly greater than for round 21174, with an initial thrust level of about 230 lb.

Figures 9 and 10 show the data from the two framing cameras for round 21173. The base of the vehicle is seen to be luminous in the frames from the camera closer to the muzzle (Figure 9). Thus, early autoignition is confirmed. A close study of the photographs from the downrange framing camera (Figure 10) shows a fully developed plume behind the projectile with a slight waviness to the plume. This plume curvature is suggestive of the yawing motion observed visually.

V. DISCUSSION

Five of the six live solid-fuel tubular ramjets fired in this test proved the structural integrity of the projectile under the design launch conditions. Autoignition occurred with all five rounds immediately at launch. Burn times varied from 1.8 to 7.7 seconds, as determined by the Hawk radar. If the anomalous 7.7 burn time projectile is excluded, a substantial variation in burn time from 1.8 to 2.8 seconds was observed. The variation in burn time seems consistent with the different projectile parameters such as nozzle throat diameter and injector diameter. Thus, a larger throat seemed to produce a shorter burn time and a higher thrust. Similarly, a larger injector diameter seemed to produce a shorter burn time and higher thrust. Unfortunately, it is not known whether the variable burn times observed are due to variations in projectile parameters or due to a possible lack of repeatable propulsion performance. Thus, a series of tests is planned with all projectile parameters held constant (to within manufacturing tolerances) to determine propulsion repeatability.

Six-degree-of-freedom computations were performed for the flight conditions of each live round fired. Drag coefficients obtained from the radar data were used to provide the correct velocity behavior. Several three-degree-of-freedom cases were also run to validate the results. These calculations all showed that the projectile impact range remained within 10.5 km at a launch elevation of 12 degrees.

Several anomalies presented themselves during these tests. The structural failure of round 21171 was probably due to a loose fit of the pins holding the nozzle section and projectile body together. The unusually long burn time associated with round 21173 was quite unexpected. A possible explanation for the long burn suggests that the fuel ablated in the combustion chamber with subsequent ignition in the expanding portion of the nozzle, thus producing an afterburner thrust. The smear photographs, however, show only the customary plume associated with normal ramjet burning, although the plume is somewhat more constricted than for other similar firings. From energy considerations, the total energy (measured from the area under the thrust-time curve) for this round was almost double that for two other projectiles. Since all thrust curves were computed on the same basis, the comparison should be valid. Energy considerations suggest that the most efficient combustion process took place for round 21173, the long burner. This would similarly suggest that the "normal" burning rounds were somewhat less efficient. Arguments have been advanced that the spin of the projectile causes the fuel in the vicinity of the injector to burn away more quickly than the remainder of the fuel in the vehicle, thus leading to an early extinction of burning because of the lack of an adequate flame holder. It may be that the fuel normally does extinguish prematurely, except for the anomalous round 21173 which, indeed, had the smallest injector diameter.

Further differences between the current tests and previous results were in the areas of reduced drag and the presence of a limit cycle yawing motion. The elliptical cowl design produced a marked reduction in the nonburning drag coefficient, a reduction of about 20%. Unfortunately, no inert projectiles were tested so that a reference drag profile for a nonburning projectile could not be accurately constructed. A reference drag curve was produced by taking the average drag from three rounds during the post-burn phase of flight. This reference drag profile was then extrapolated to include the burning Mach number region. An examination of previous test results with the higher drag live and inert projectiles (Ref. 3) showed that the inert projectile had consistently higher drag than the live projectile during the nonburning phase of flight.

The limit-cycle, small amplitude yawing motion has been variously estimated at less than five degrees of yaw. No yawing motion had been observed in previous flight tests. The persistent small yaw probably resulted from the changed physical characteristics of the projectile in the current tests. The overall projectile weight was reduced by about one-fifth. The static margin was reduced by a rearward movement of the center of gravity. The gyroscopic stability factor was reduced by about 50%. Six-degree-of-freedom computations using the current best estimates for aerodynamic coefficients showed a marked tendency toward flight instability, given the current projectile physical characteristics. Tests within the BRL Transonic Range Facility are planned for the immediate future in order to accurately determine the aerodynamic properties of several versions of the SFRJ.

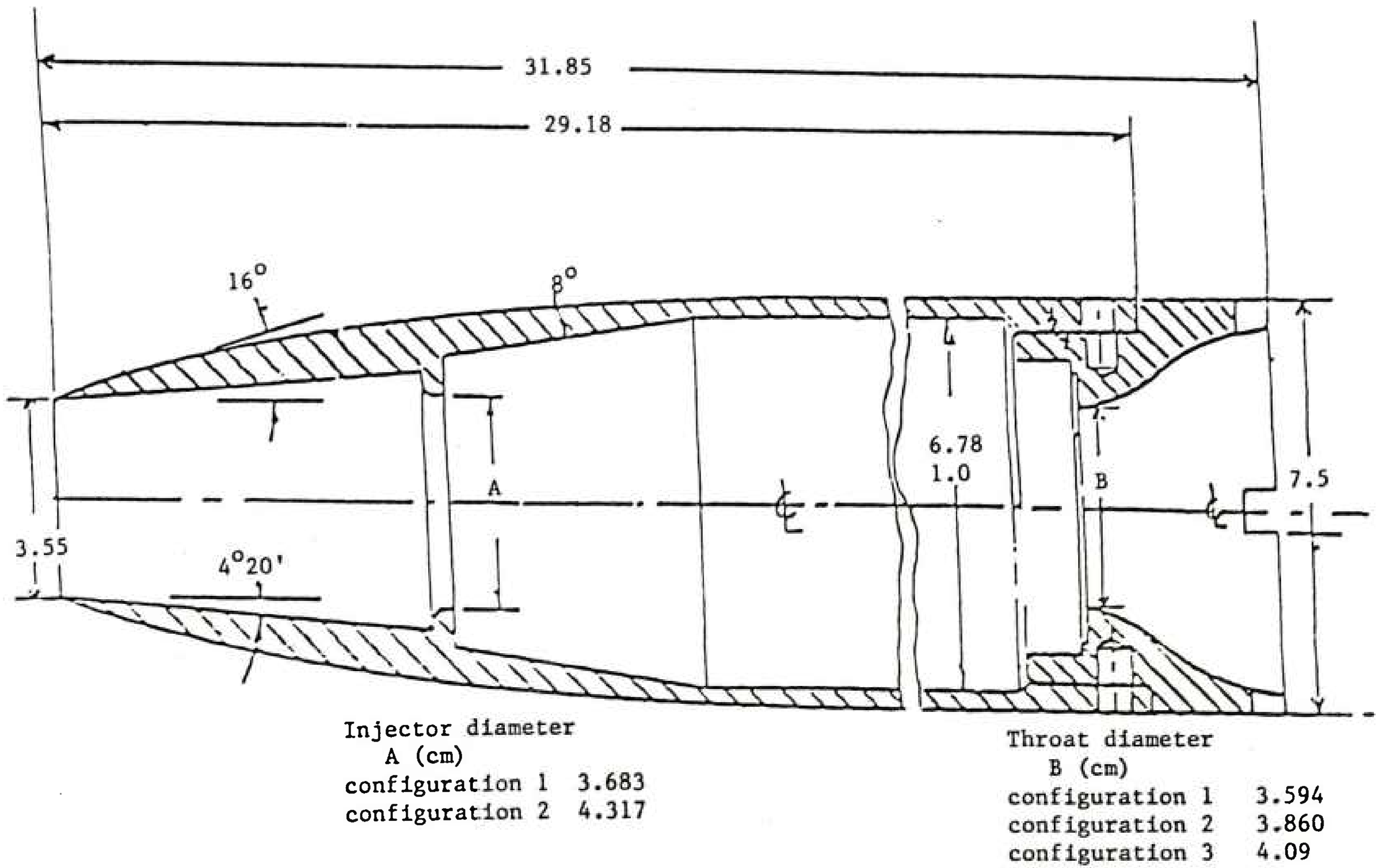

Figure 1. Sketch of the Design of the 75mm Tubular SFRJ Projectile.

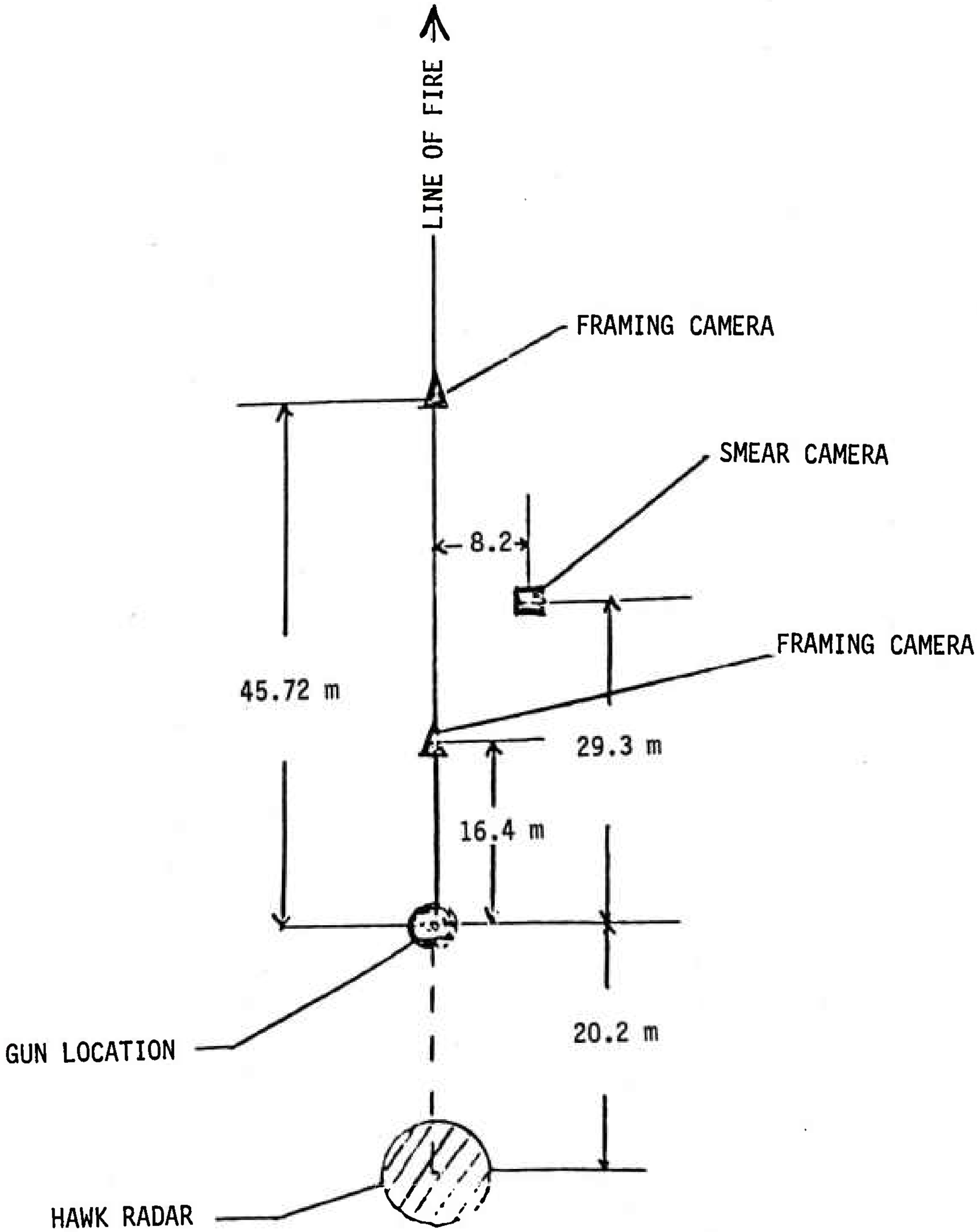

Figure 2. Sketch of the Test Layout.

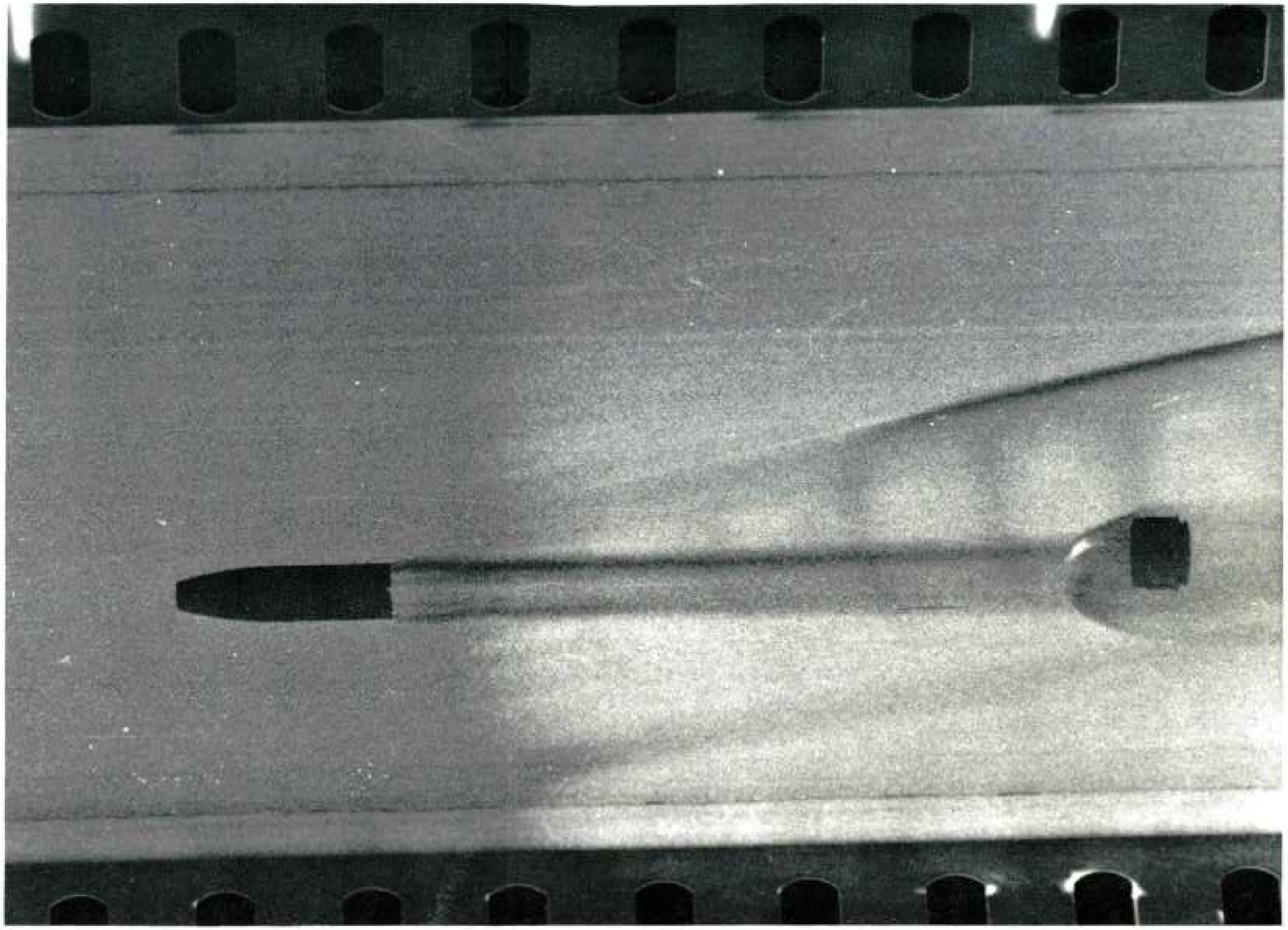

Figure 3. Round 21170---39.4 Meters From the Muzzle.

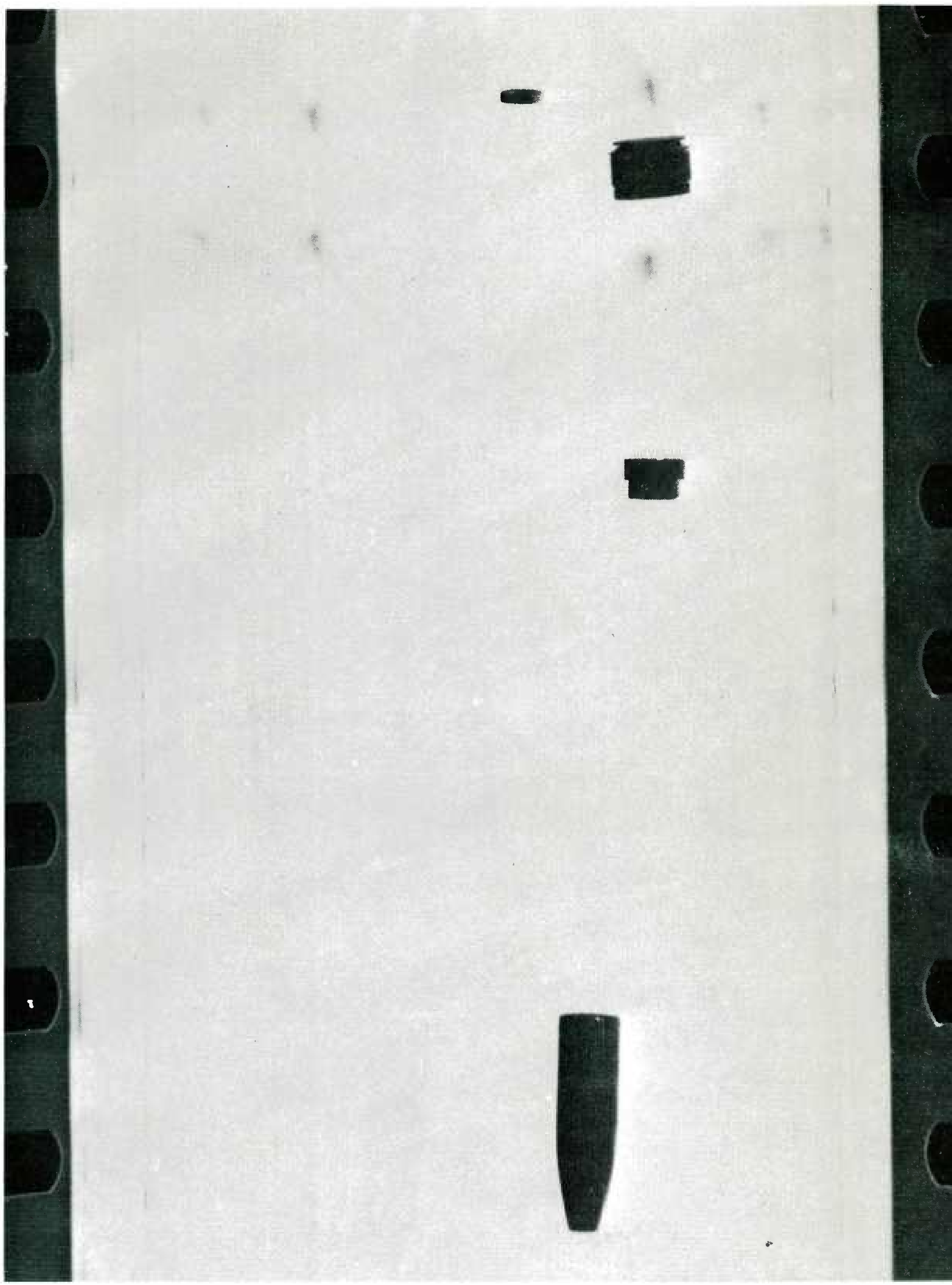

Figure 4. Round 21171---39.4 Meters From the Muzzle.

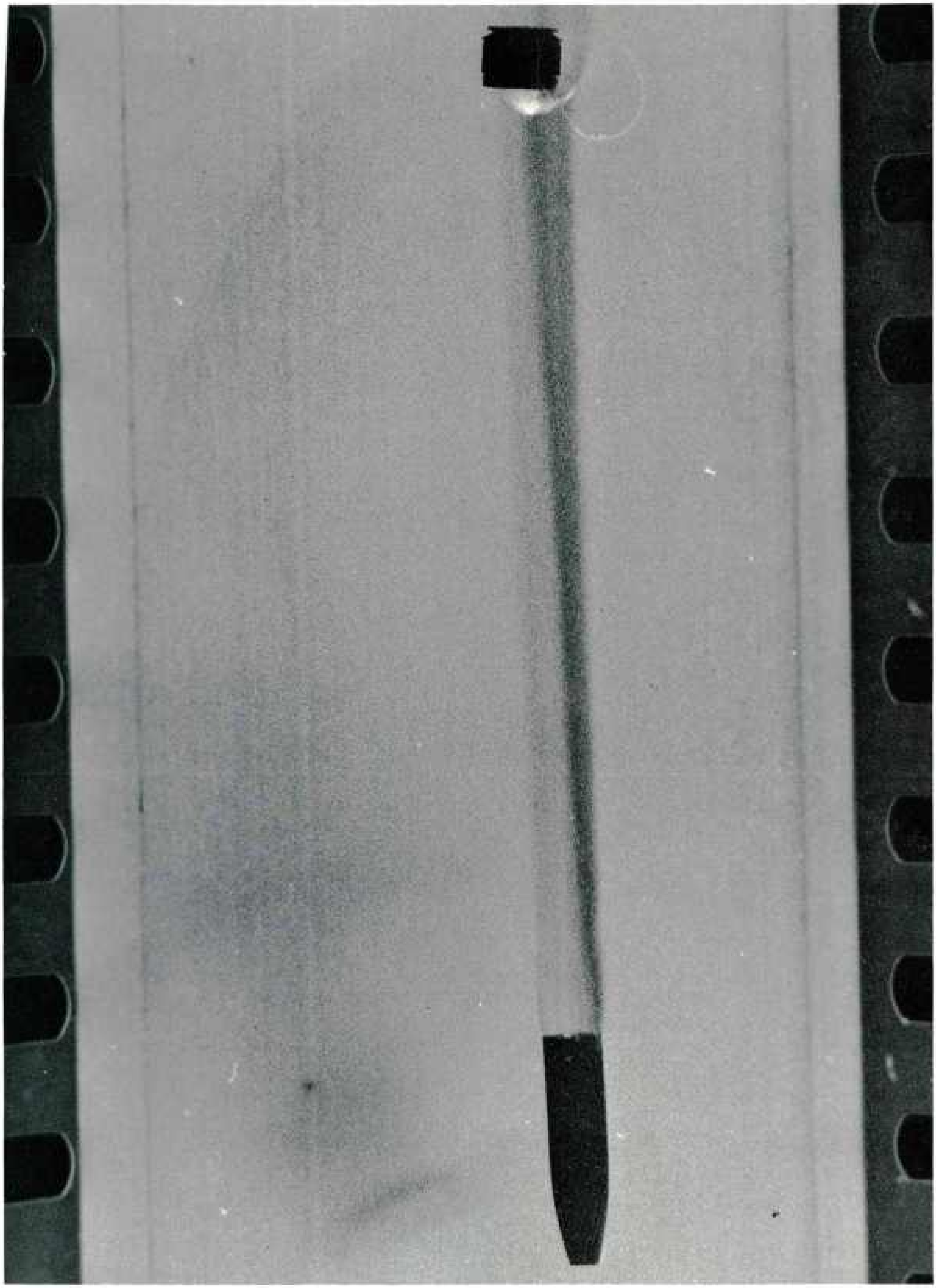

Figure 5. Round 21172--39.4 Meters From the Muzzle.

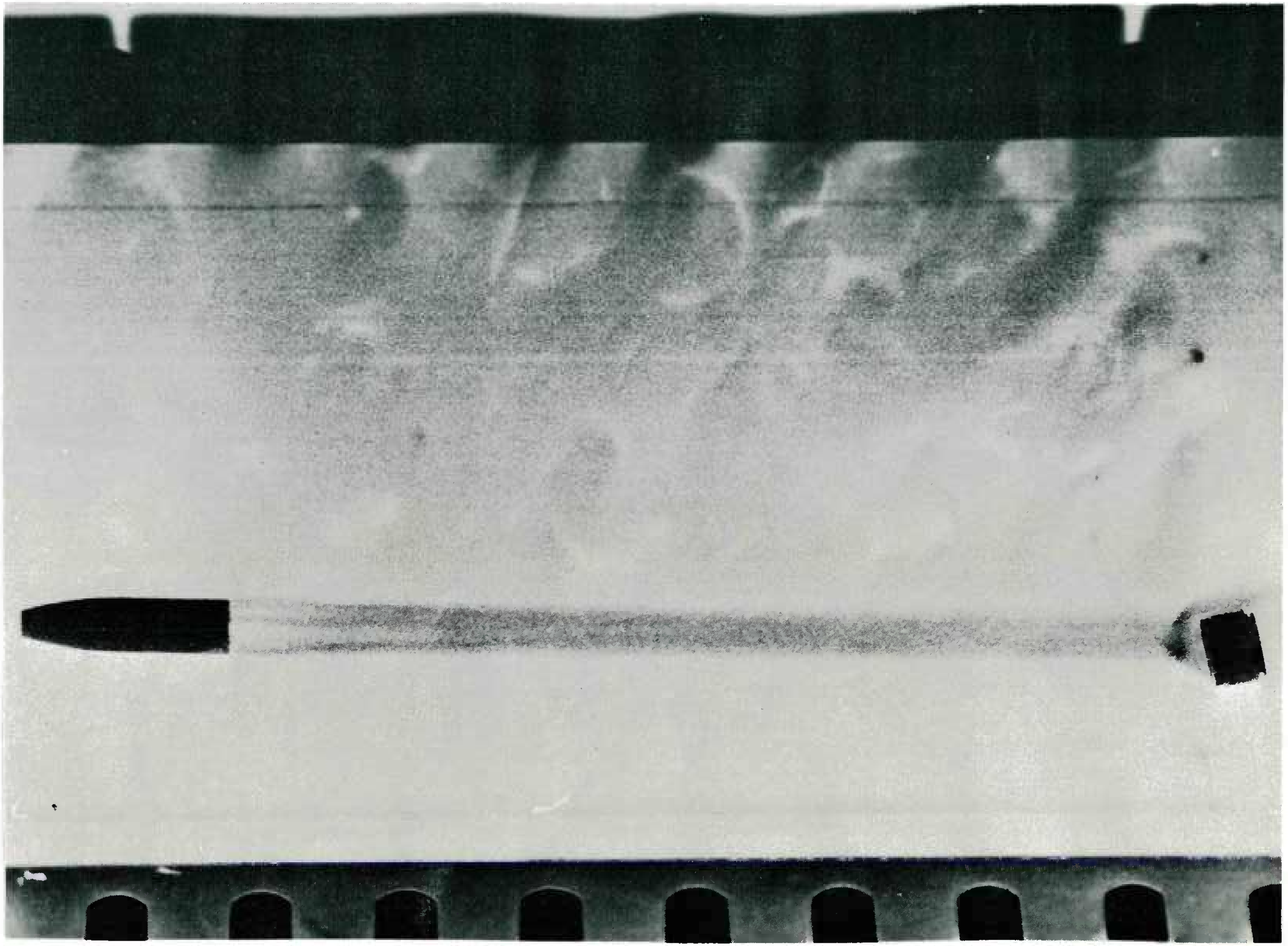

Figure 6. Round 21173---39.4 Meters From the Muzzle.

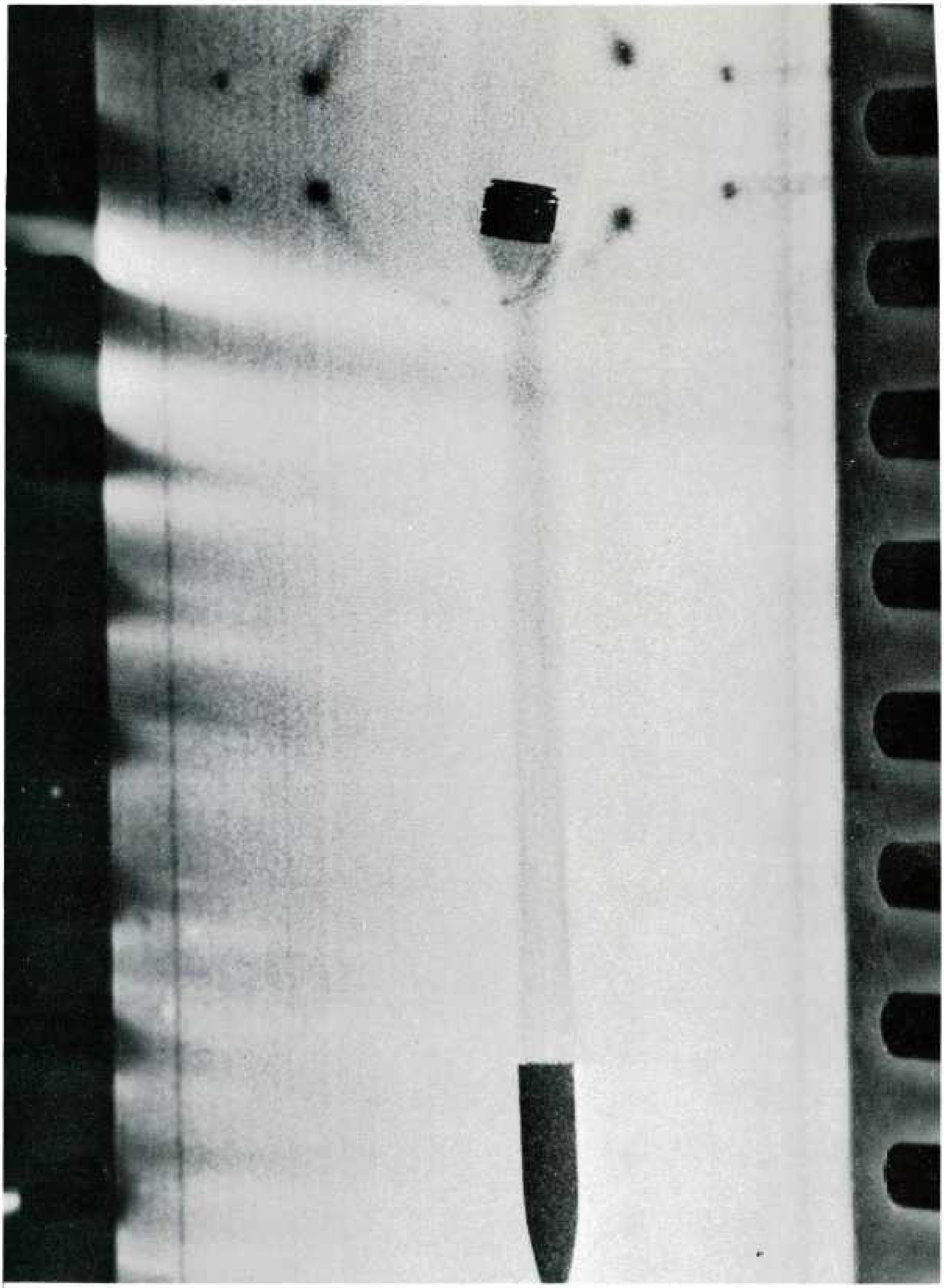

Figure 7. Round 21174--39.4 Meters From the Muzzle.

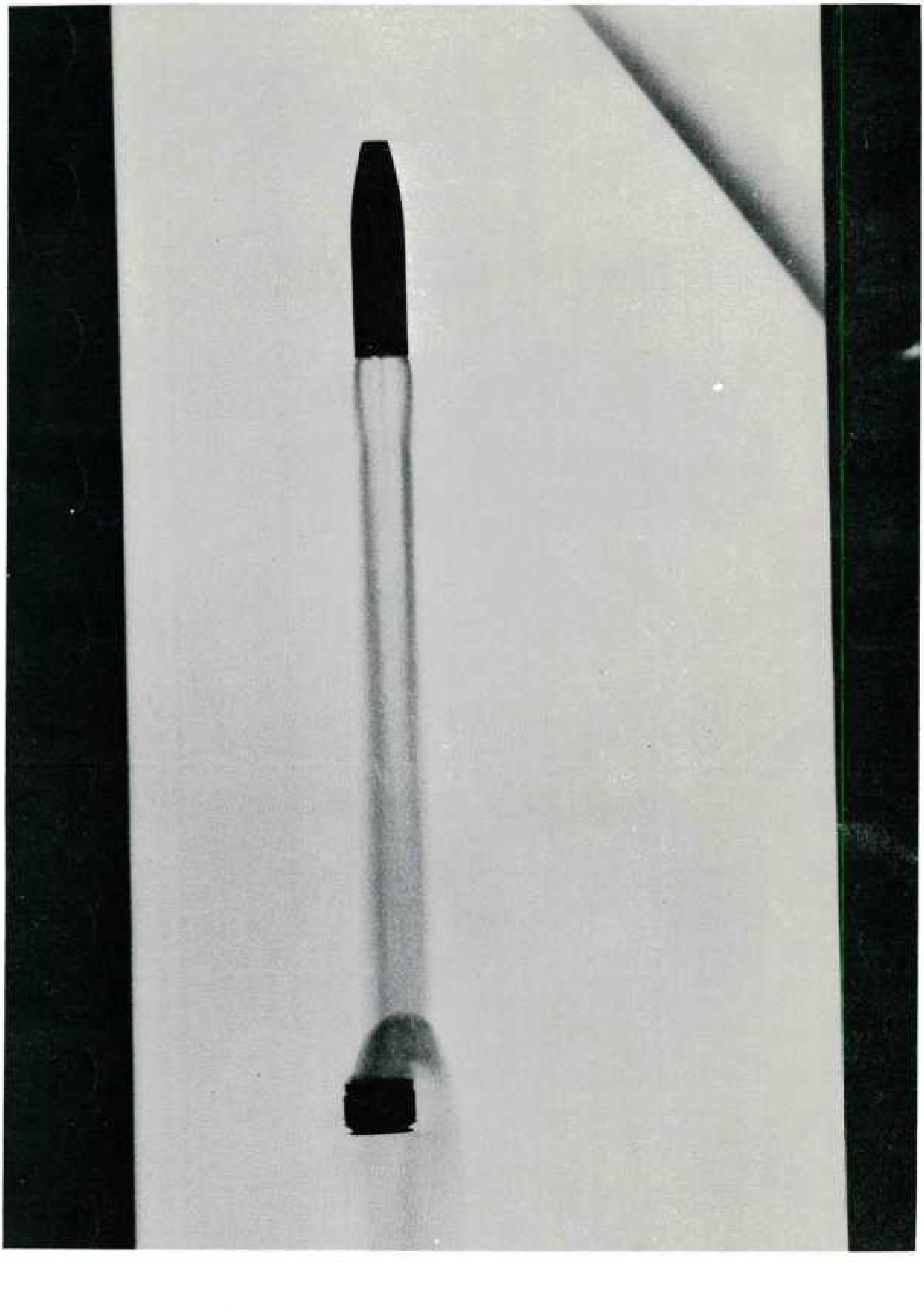

Figure 8. Round 21175---39.4 Meters From the Muzzle.

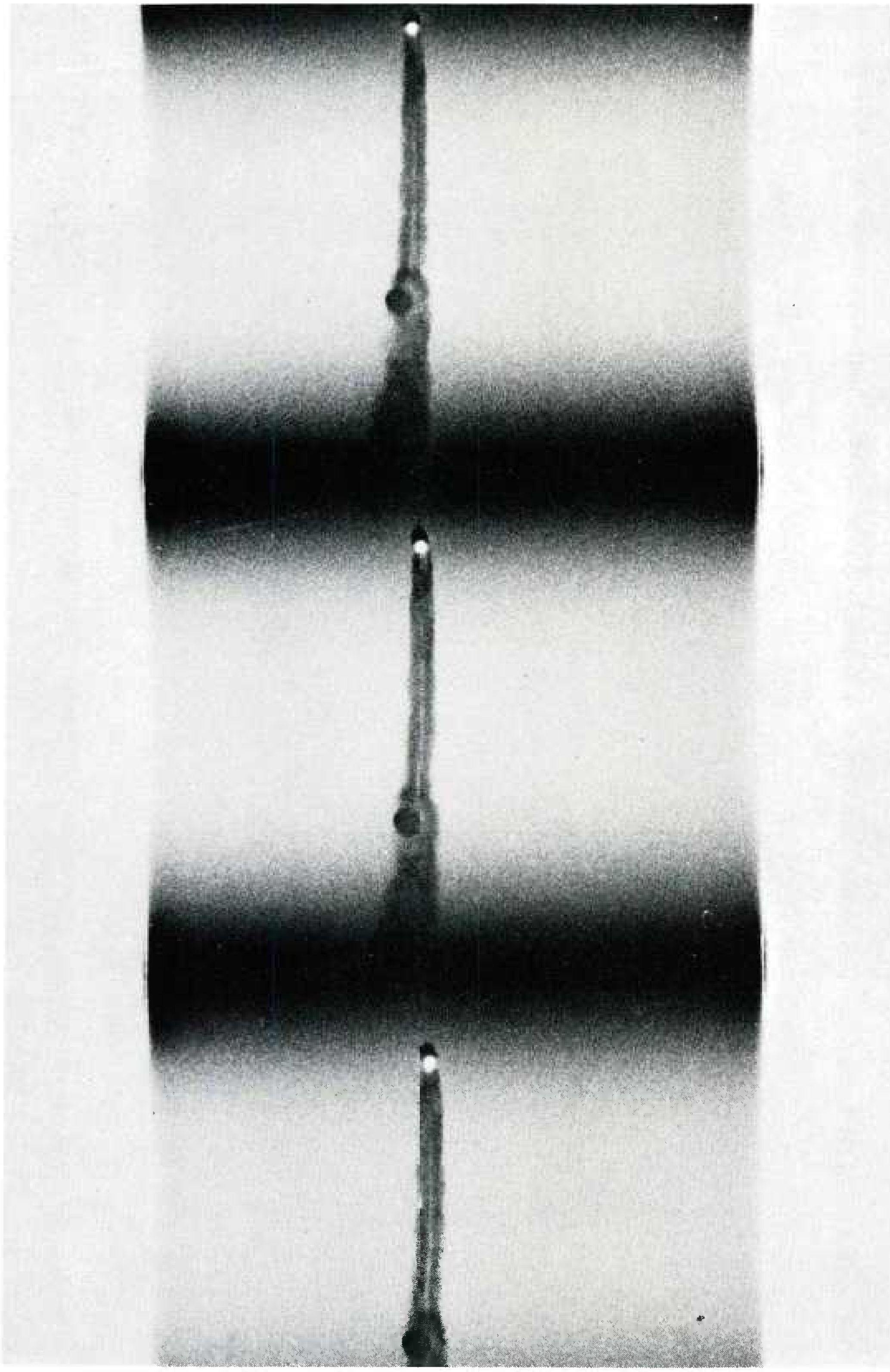

Figure 9. Round 21173--16.4 Meters From the Muzzle.

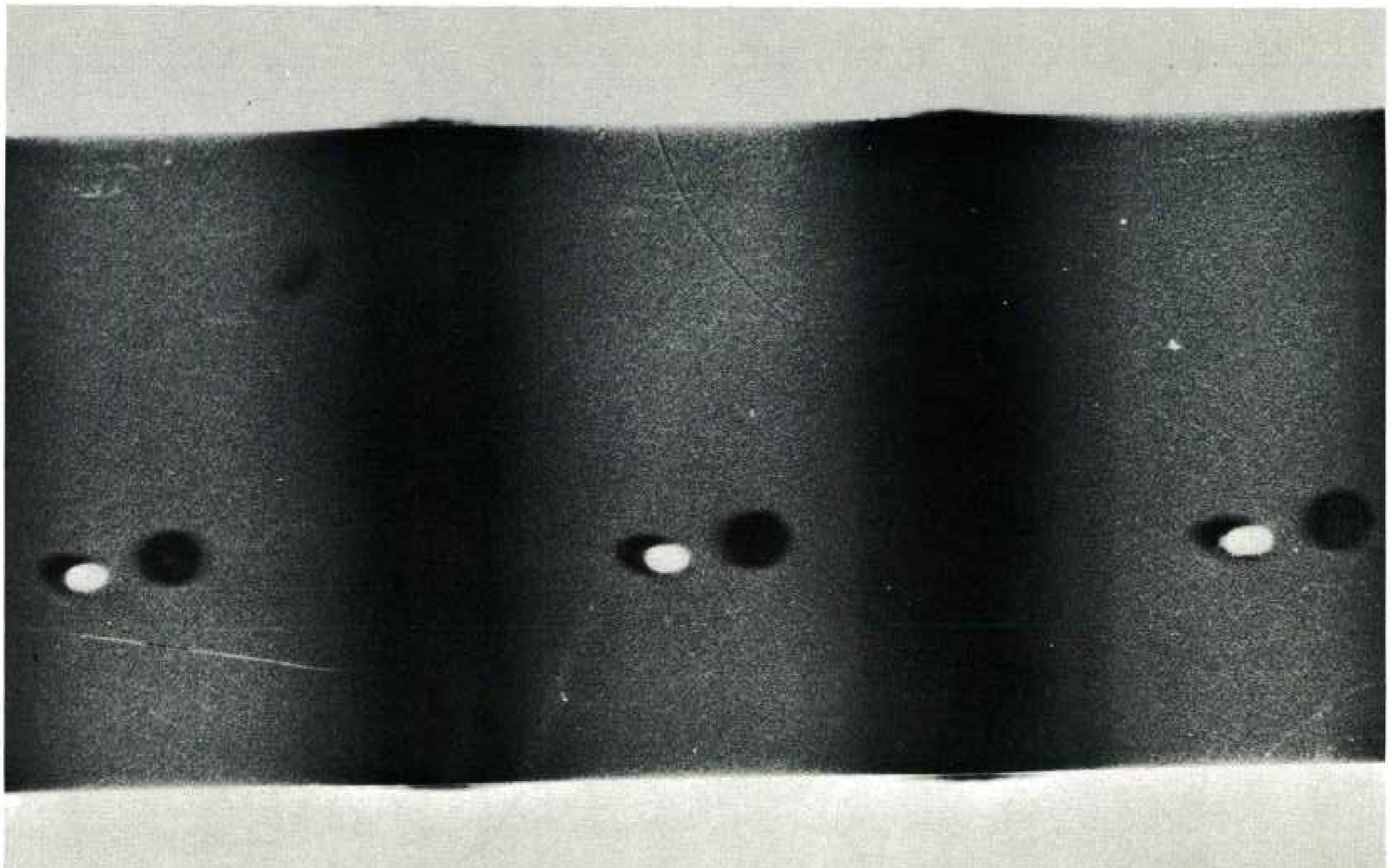

Figure 10. Round 21173---45.7 Meters From the Muzzle.

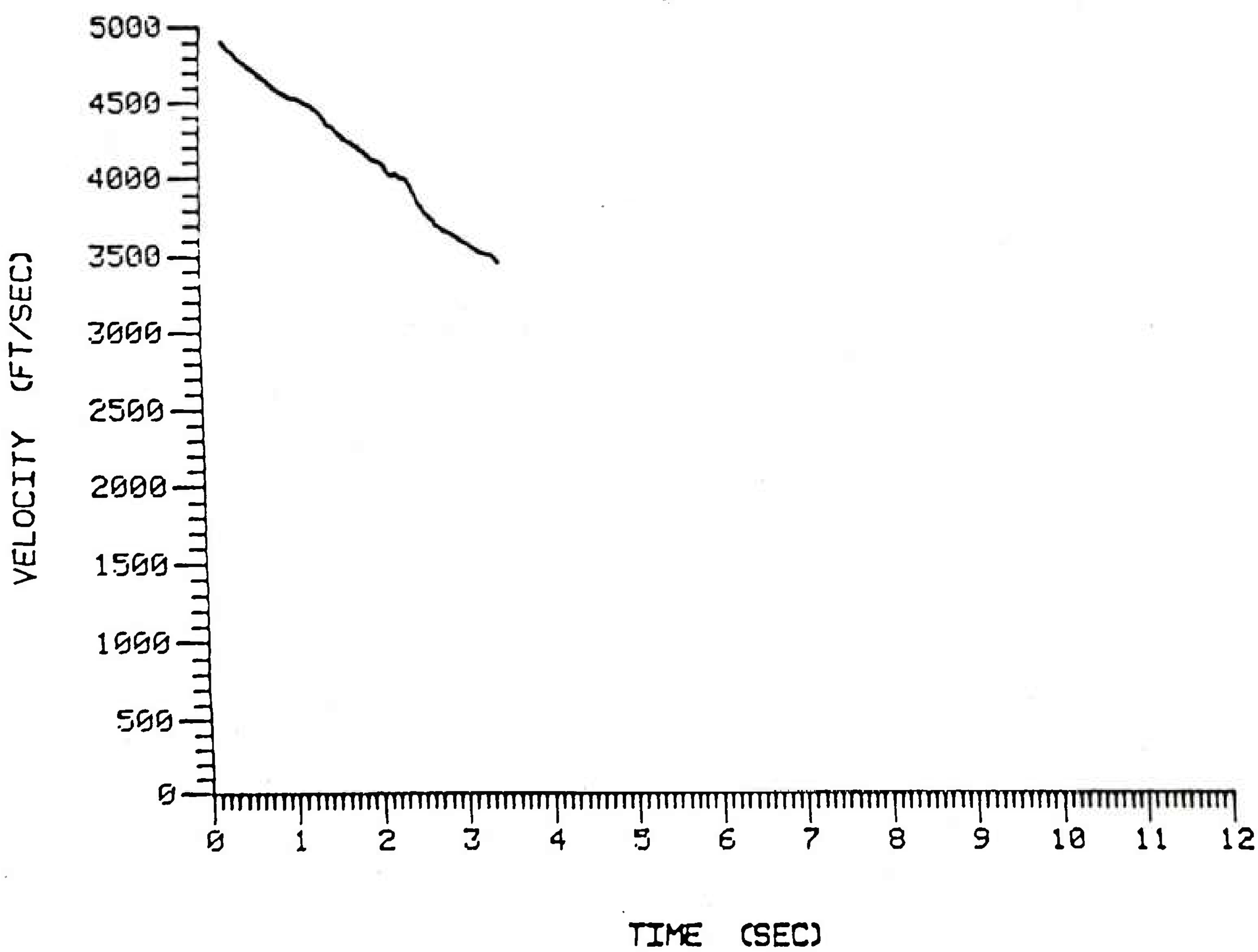

Figure 11. Velocity From Hawk vs Time (Round 21170).

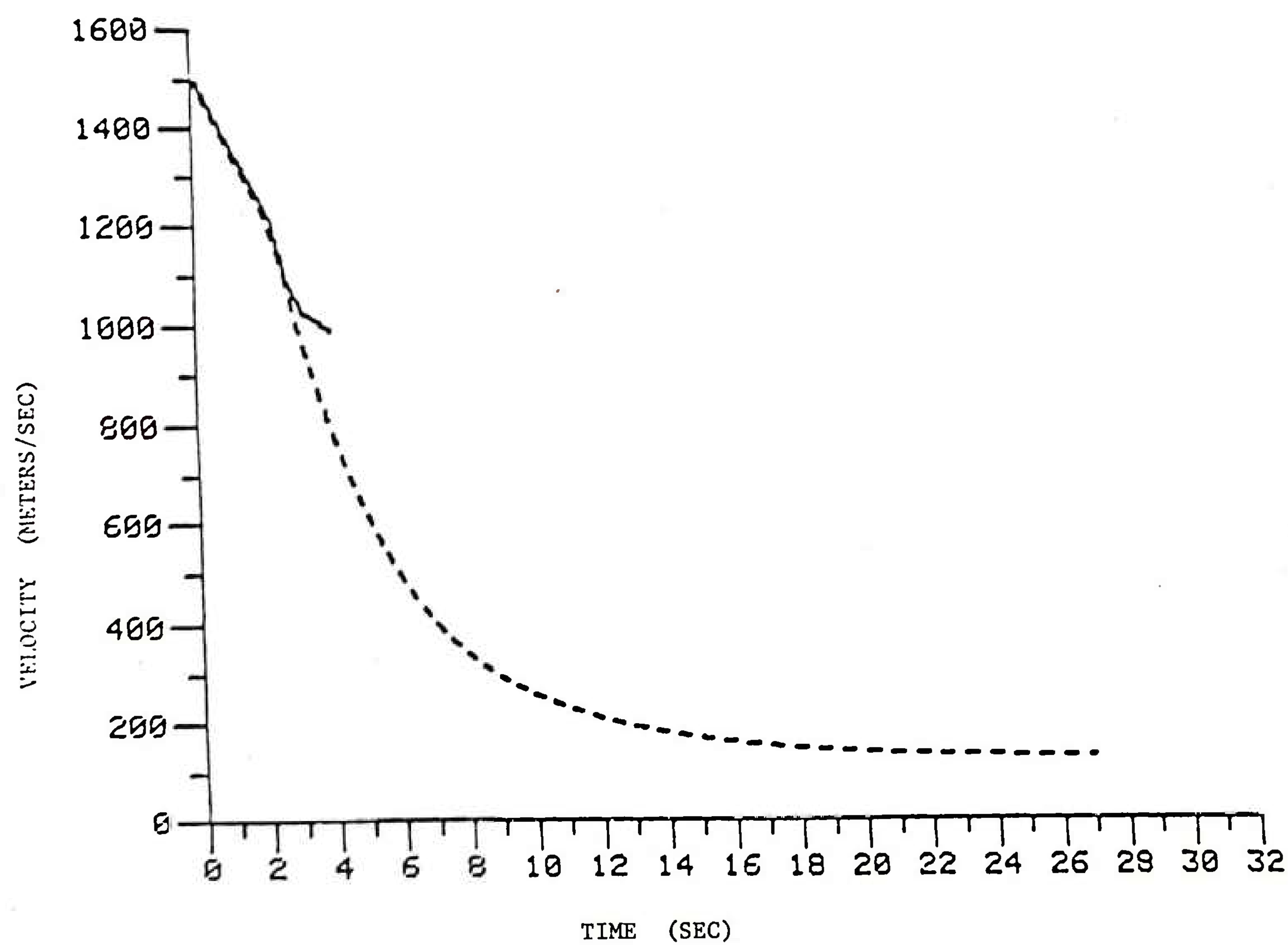

Figure 12. The Comparison of Velocities From Hawk and 6-DOF vs Time (Round 21170).

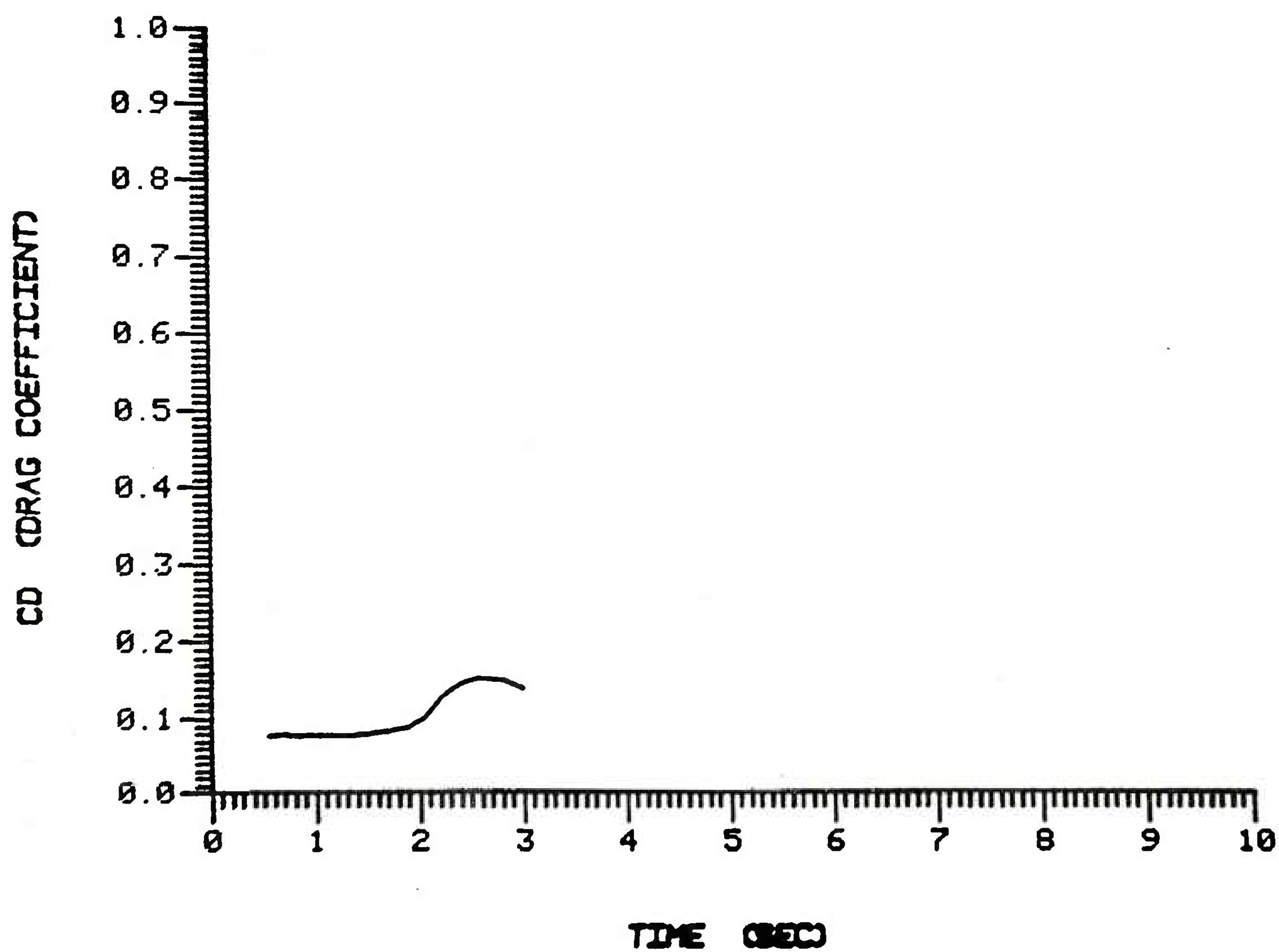

Figure 13. The Drag Coefficient C_D vs Time (Round 21170).

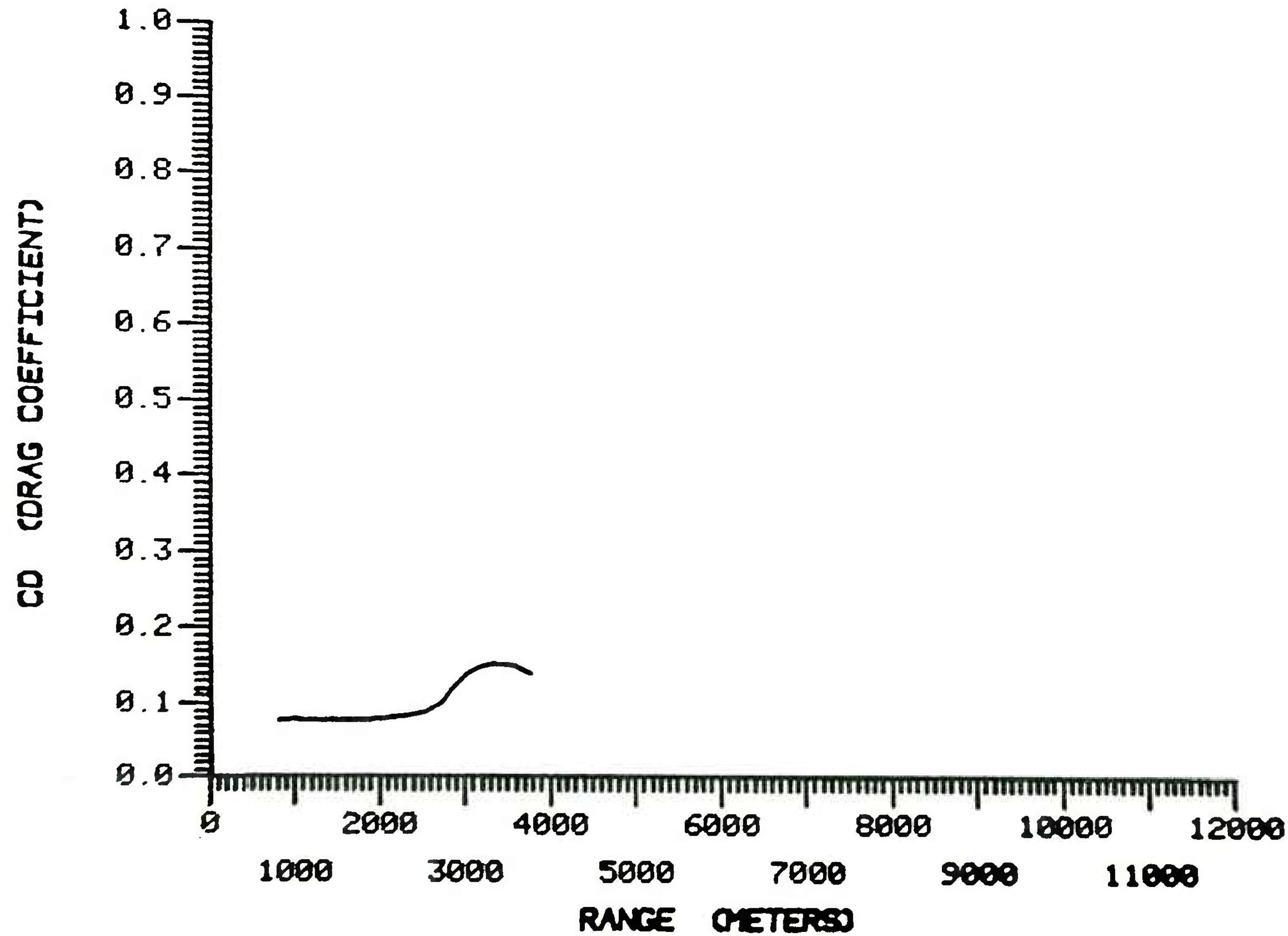

Figure 14. The Drag Coefficient C_D vs Range (Round 21170).

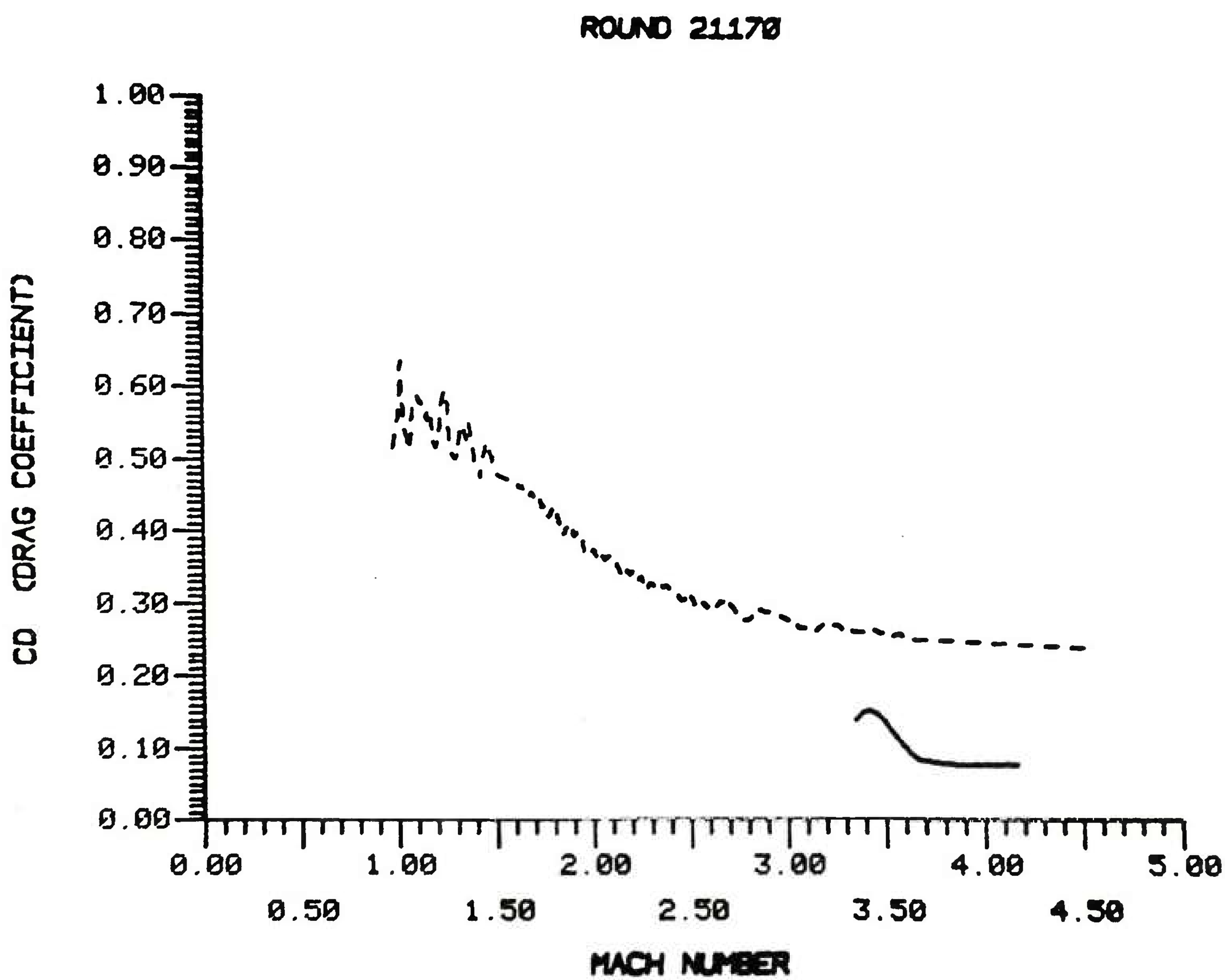

Figure 15. The Drag Coefficient C_D vs Mach Number (Round 21170).

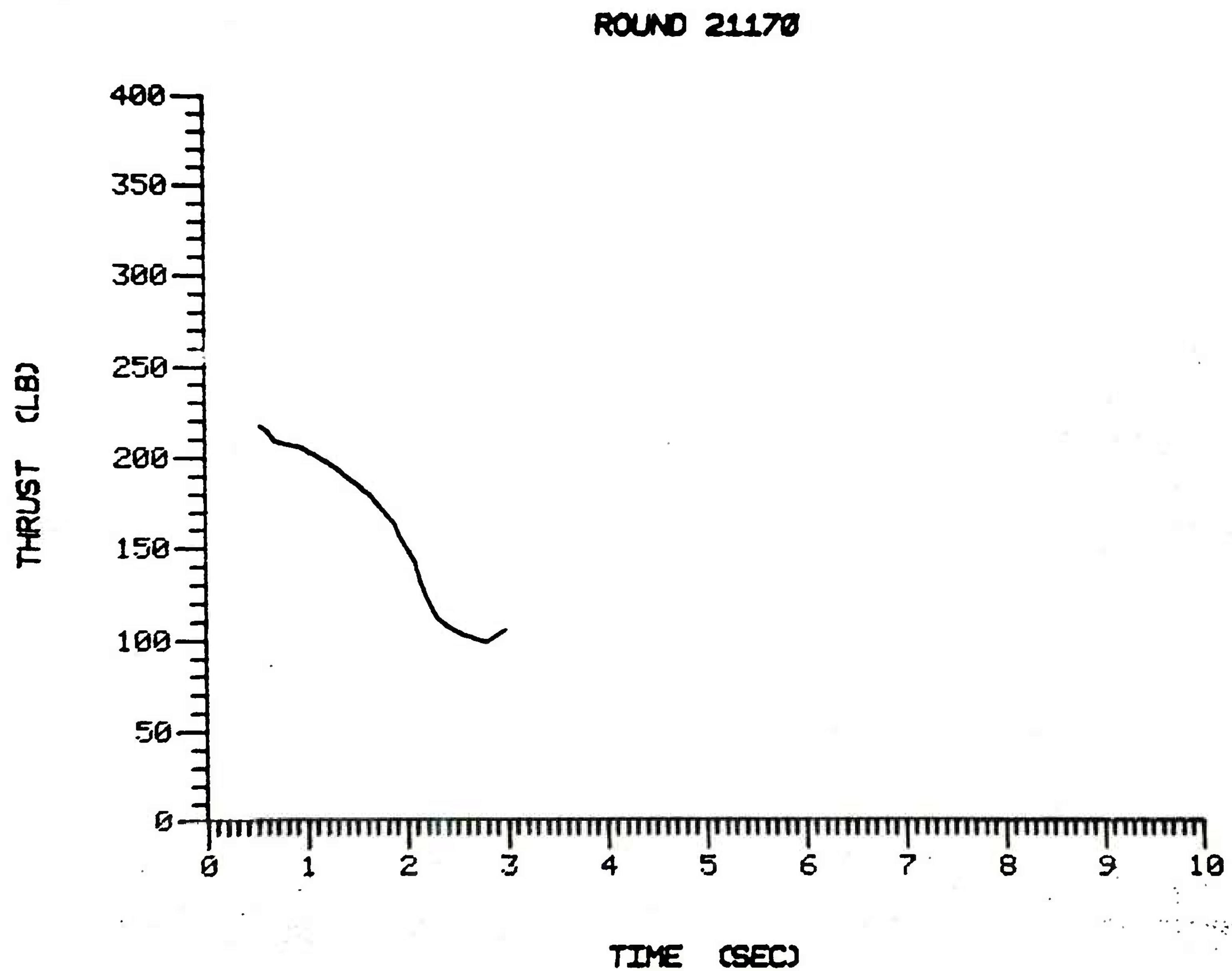

Figure 16. Thrust vs Time (Round 21170).

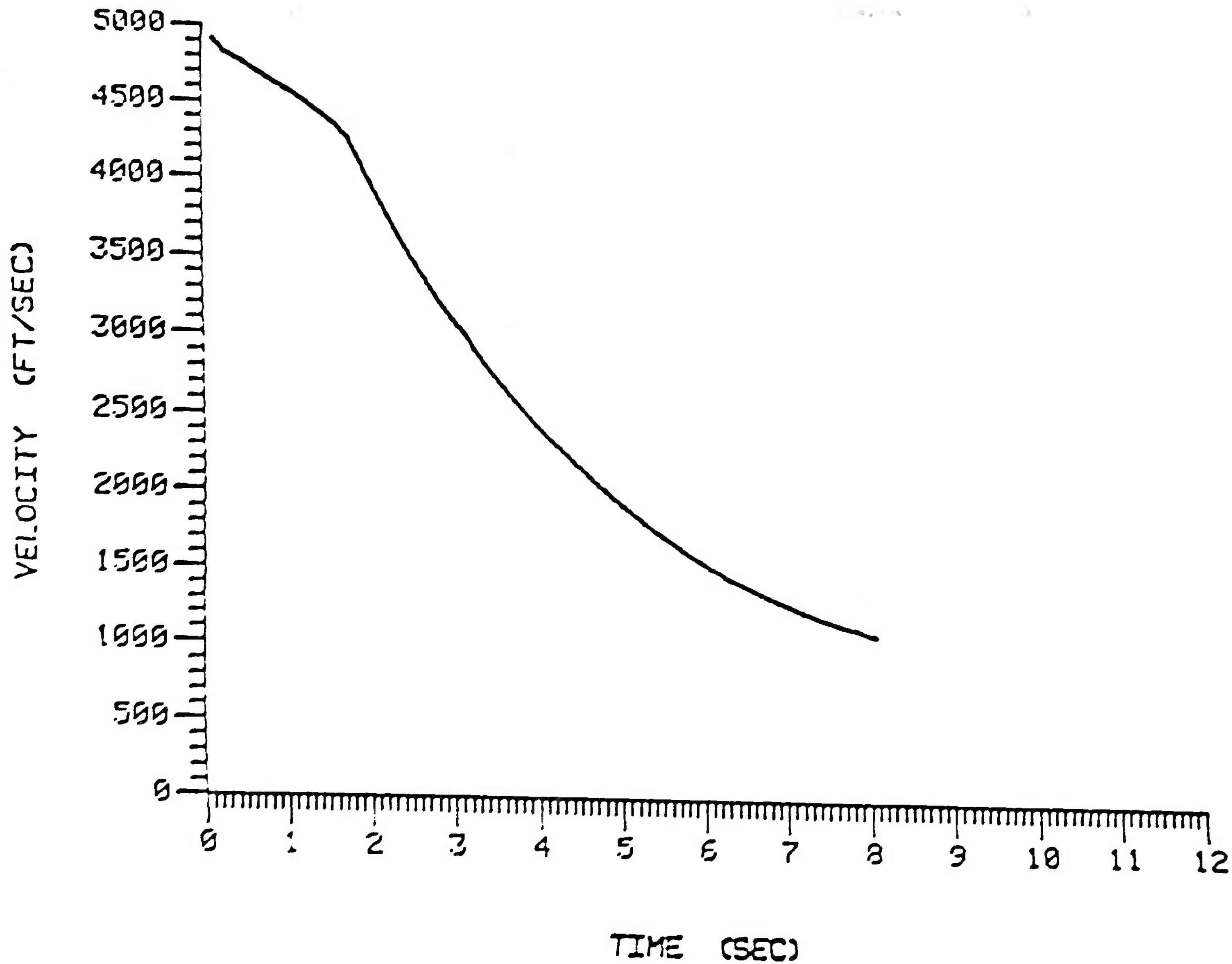

Figure 17. Velocity From Hawk vs Time (Round 21172).

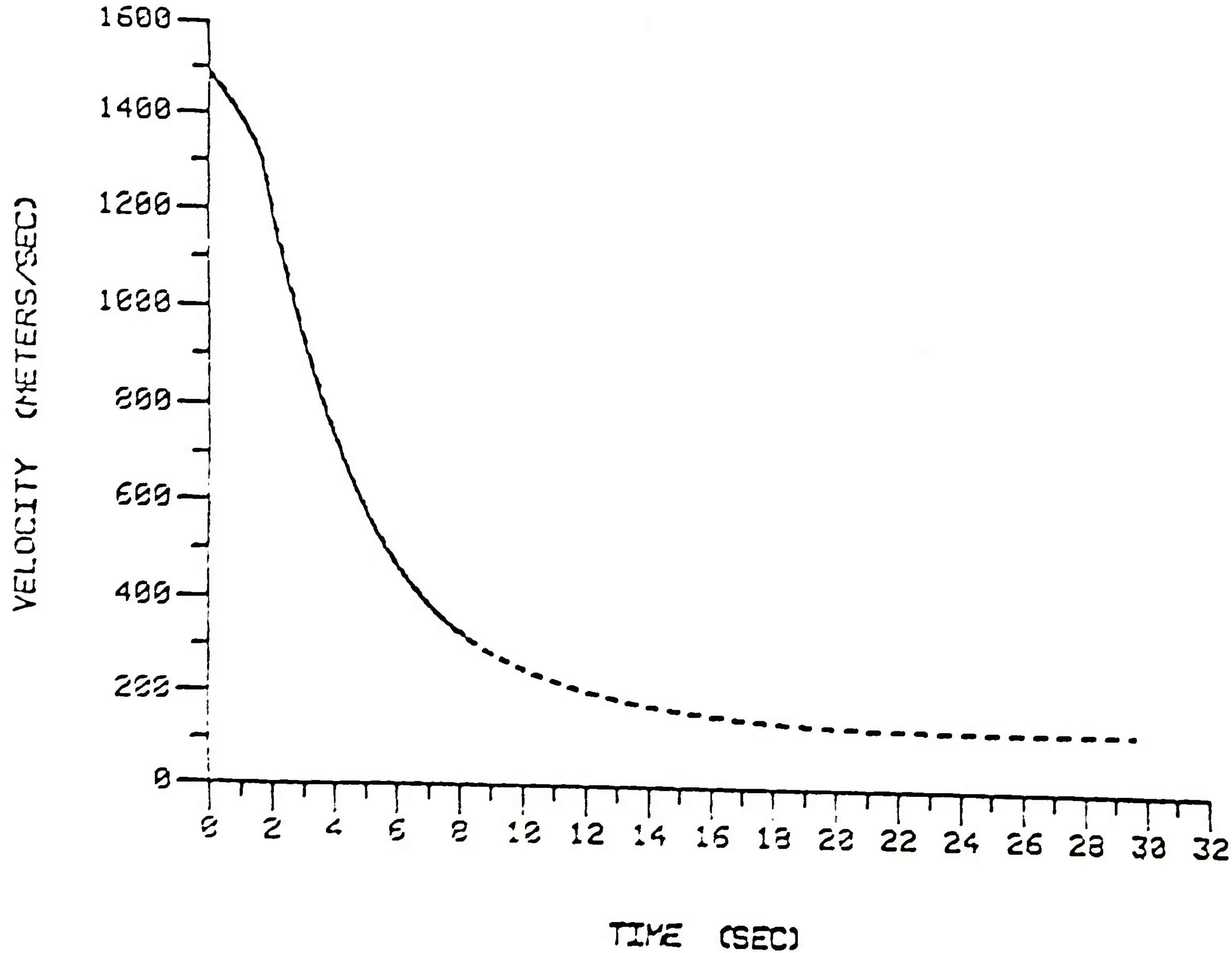

Figure 18. The Comparison of Velocities From Hawk and 6-DOF vs Time (Round 21172).

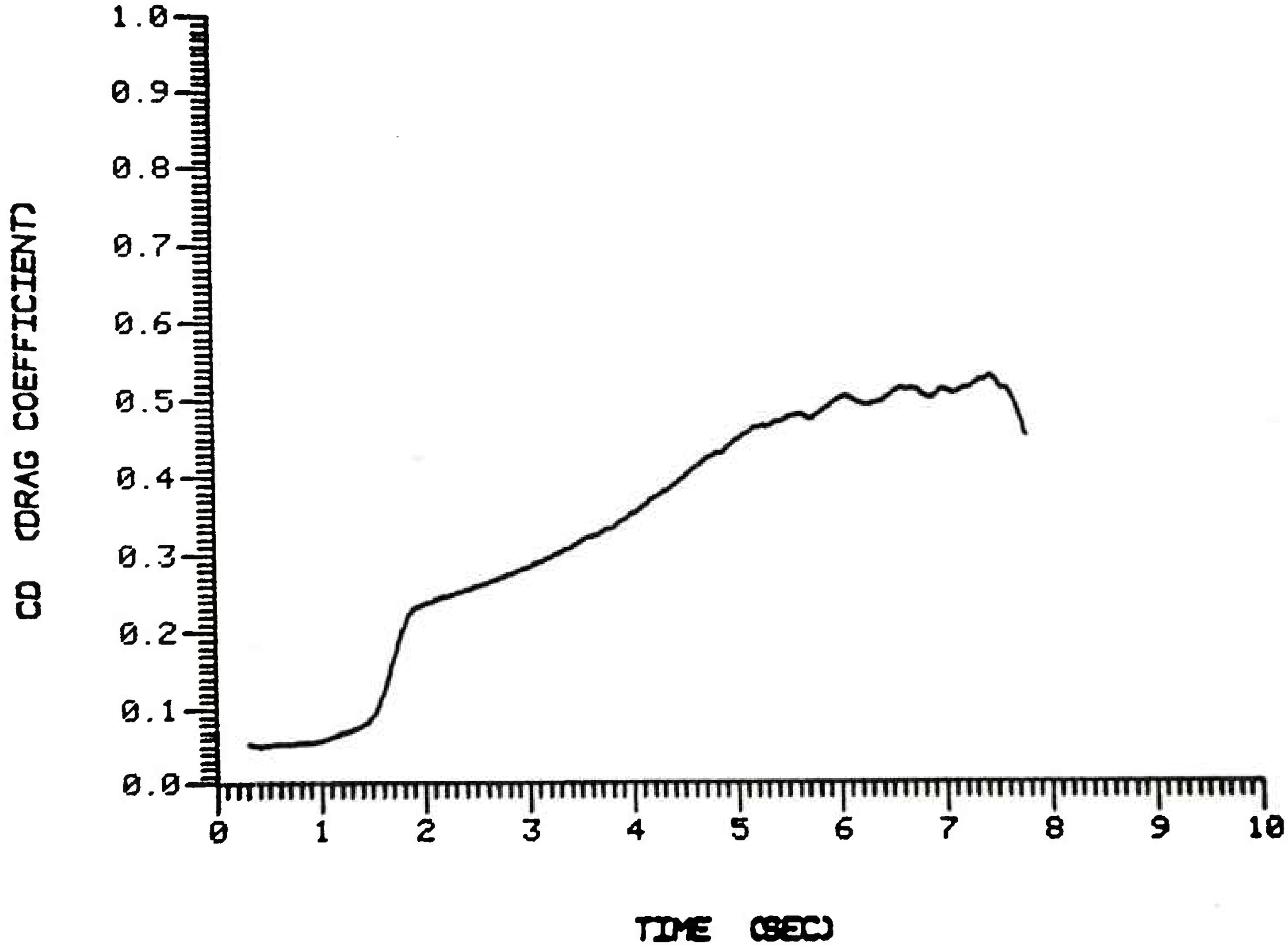

Figure 19. The Drag Coefficient C_D vs Time (Round 21172).

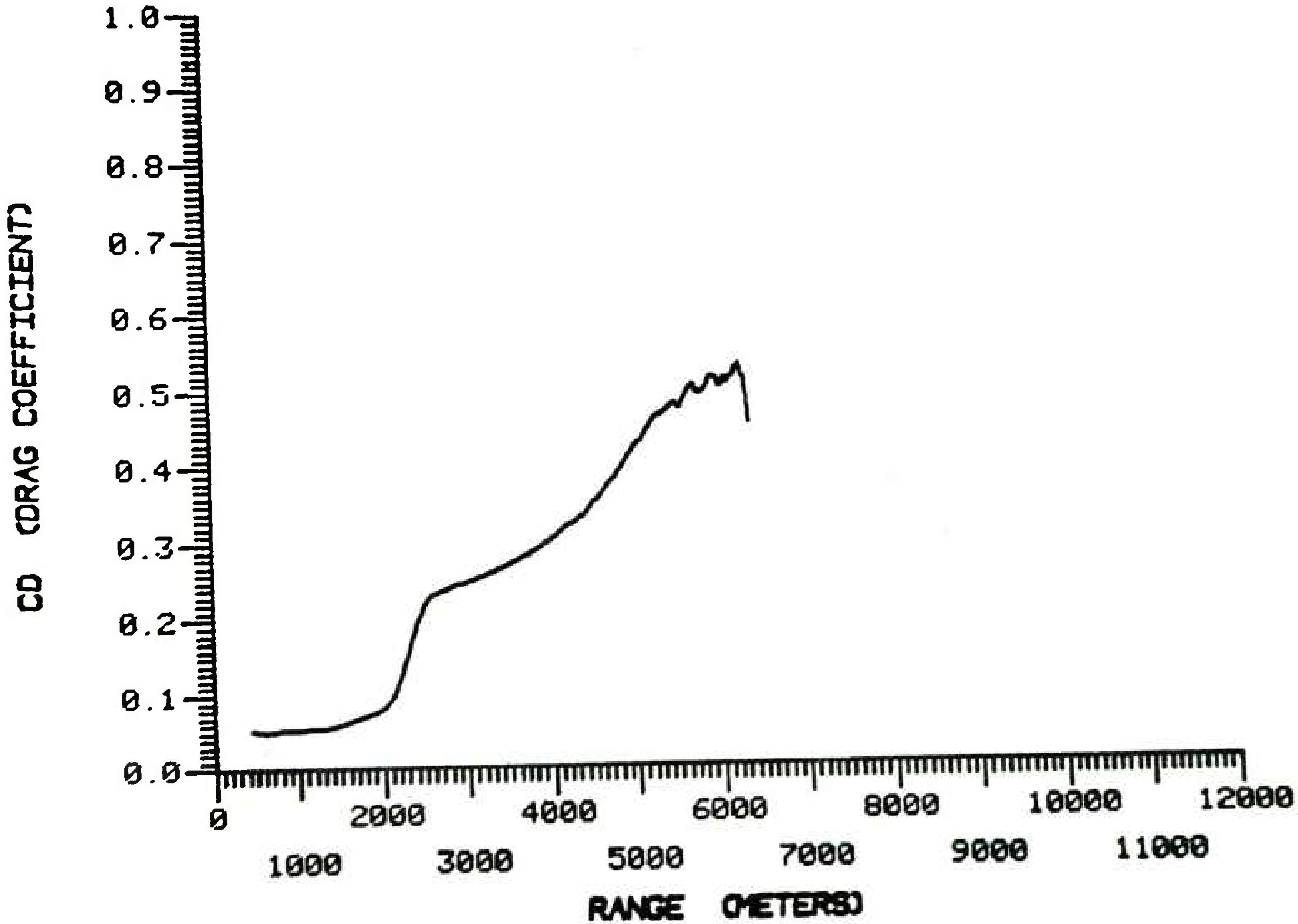

Figure 20. The Drag Coefficient C_D vs Range (Round 21172).

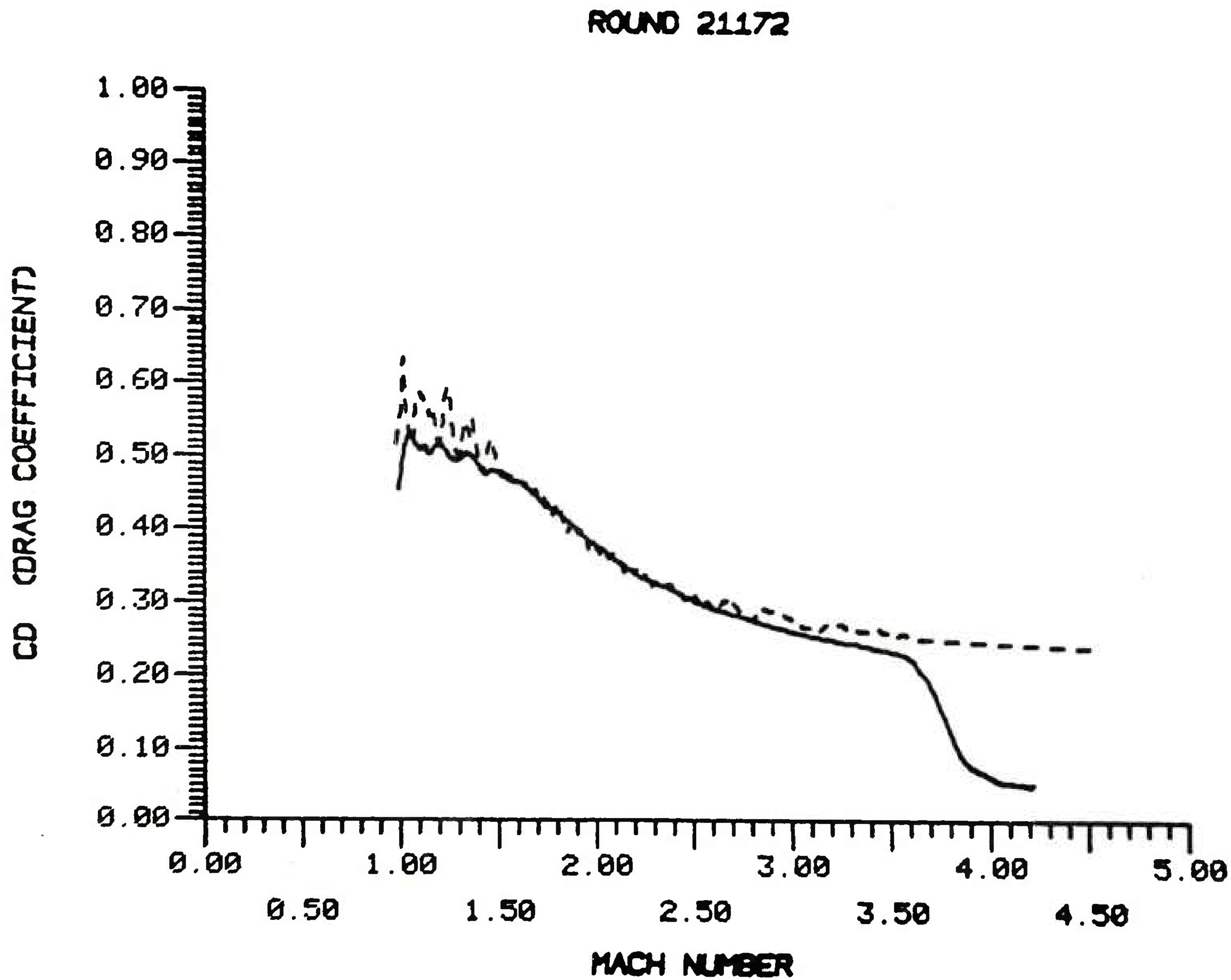

Figure 21. The Drag Coefficient C_D vs Mach Number (Round 21172).

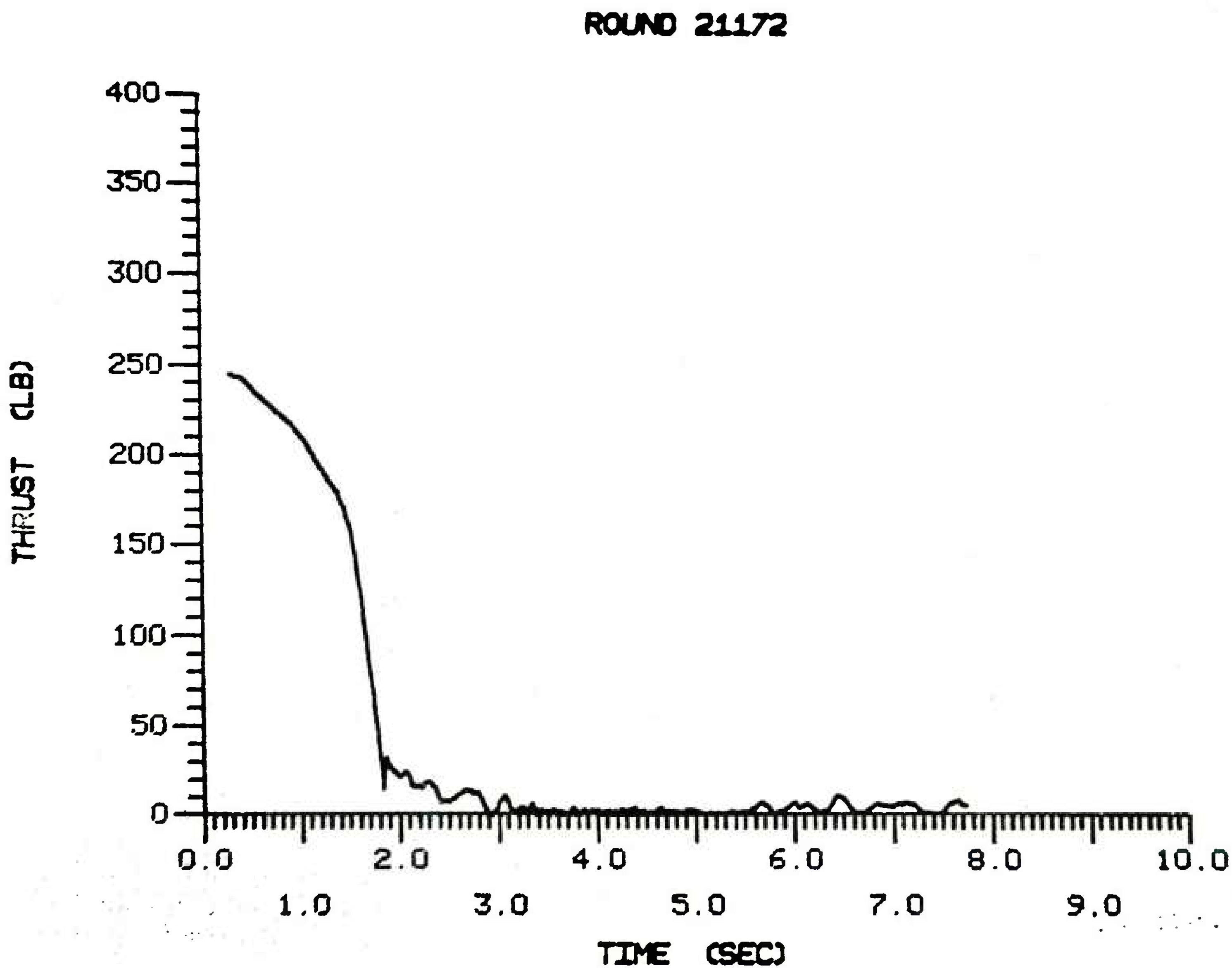

Figure 22. Thrust vs Time (Round 21172).

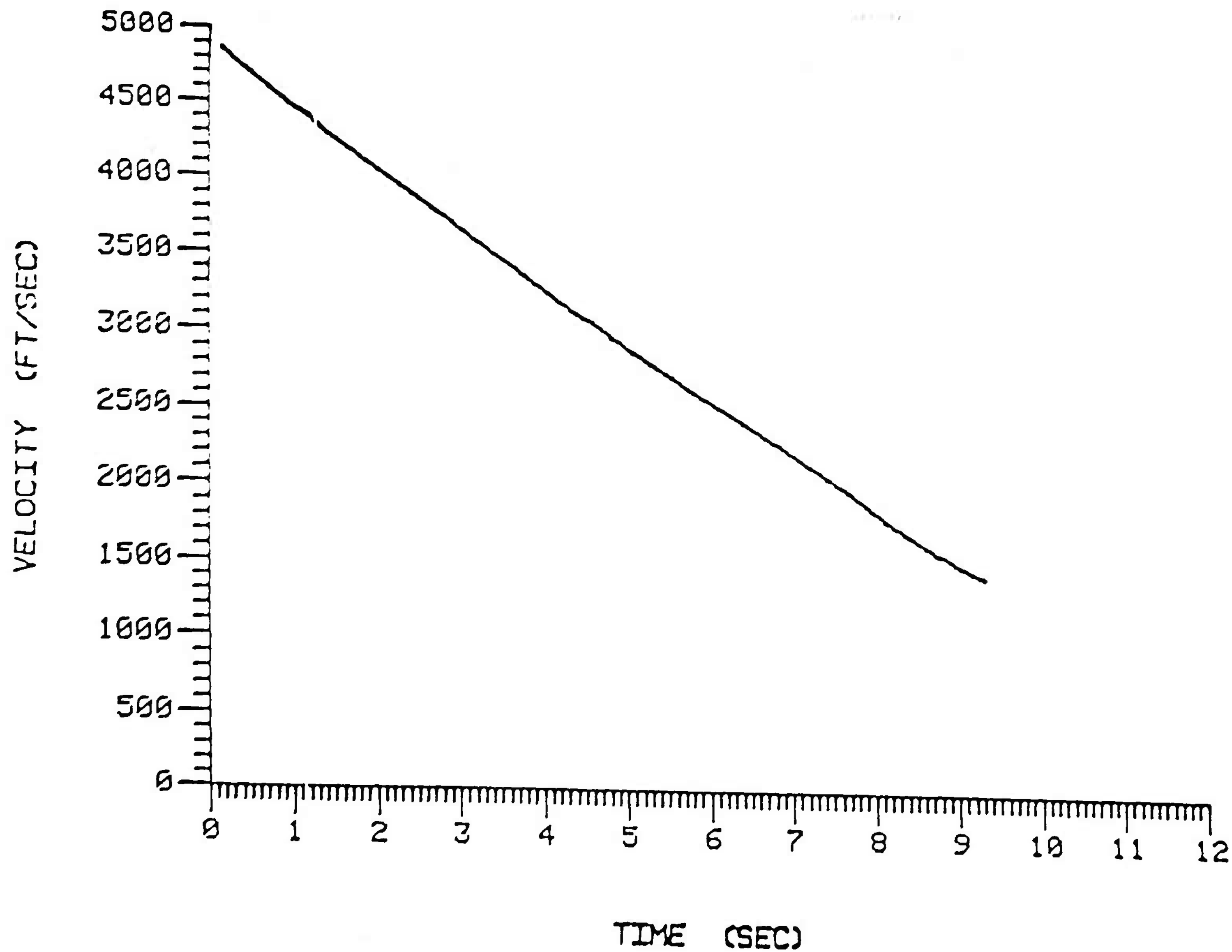

Figure 23. Velocity From Hawk vs Time (Round 21173).

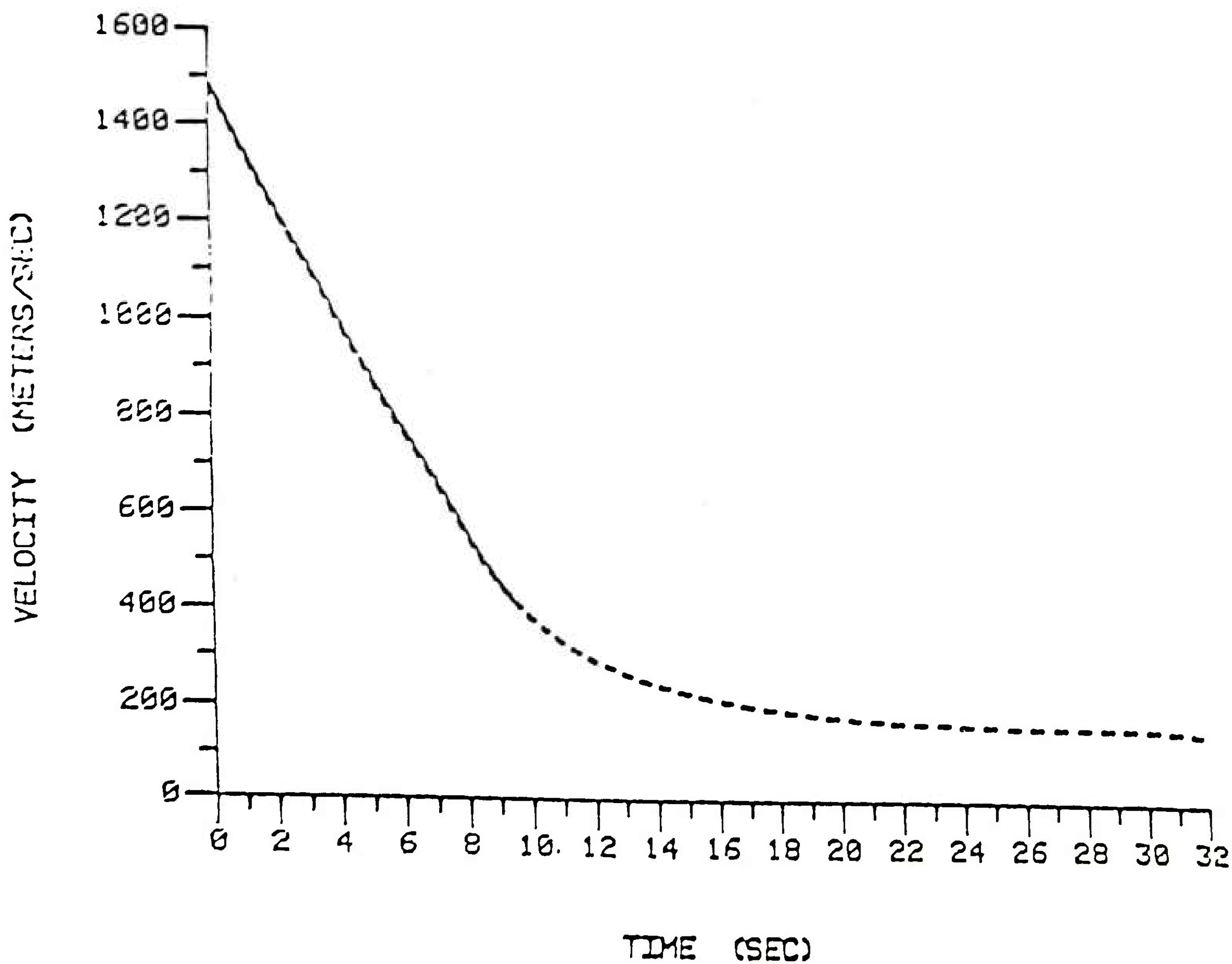

Figure 24. The Comparison of Velocities From Hawk and 6-DOF vs Time (Round 21173).

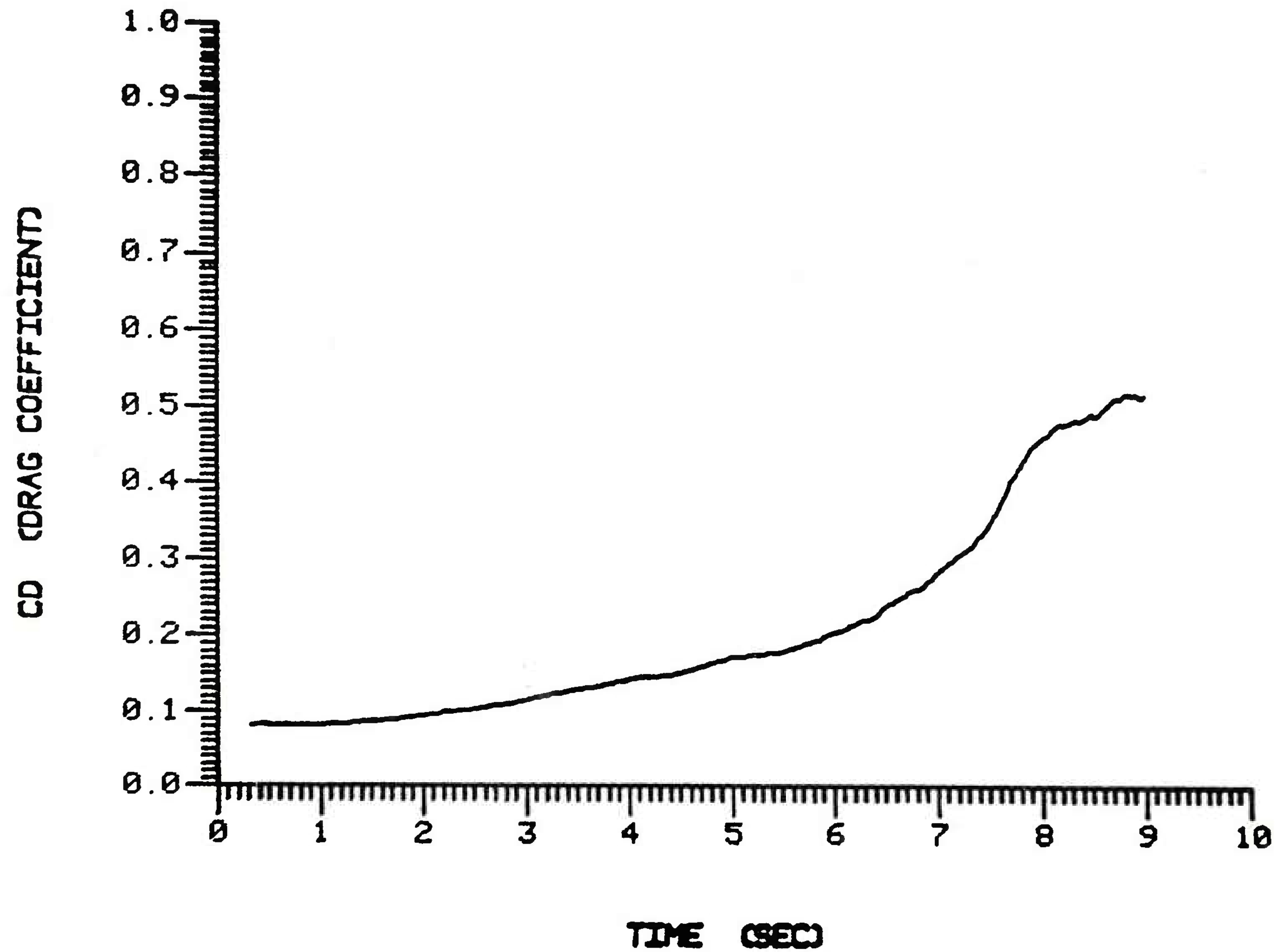

Figure 25. The Drag Coefficient C_D vs Time (Round 21173).

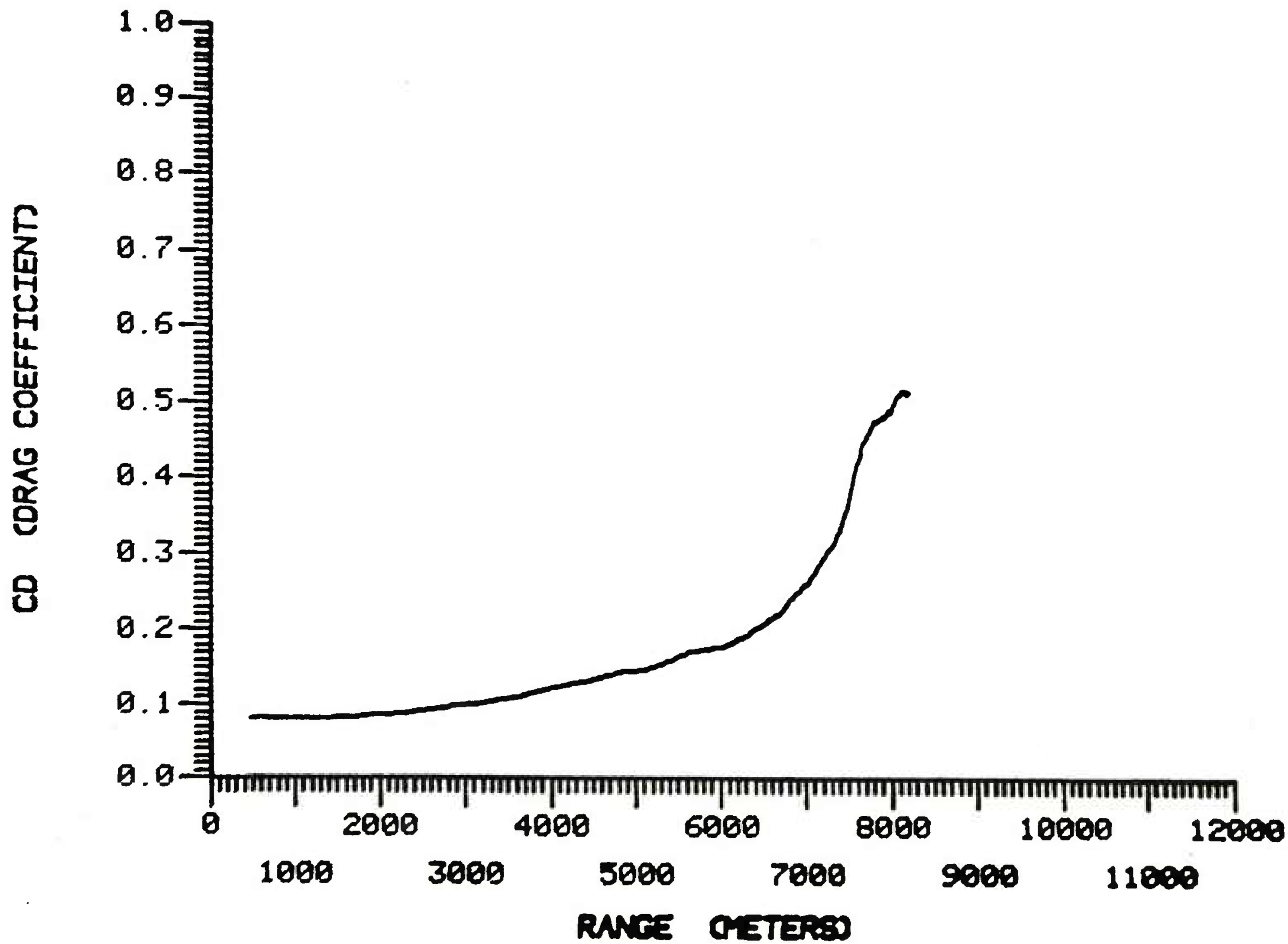

Figure 26. The Drag Coefficient C_D vs Range (Round 21173).

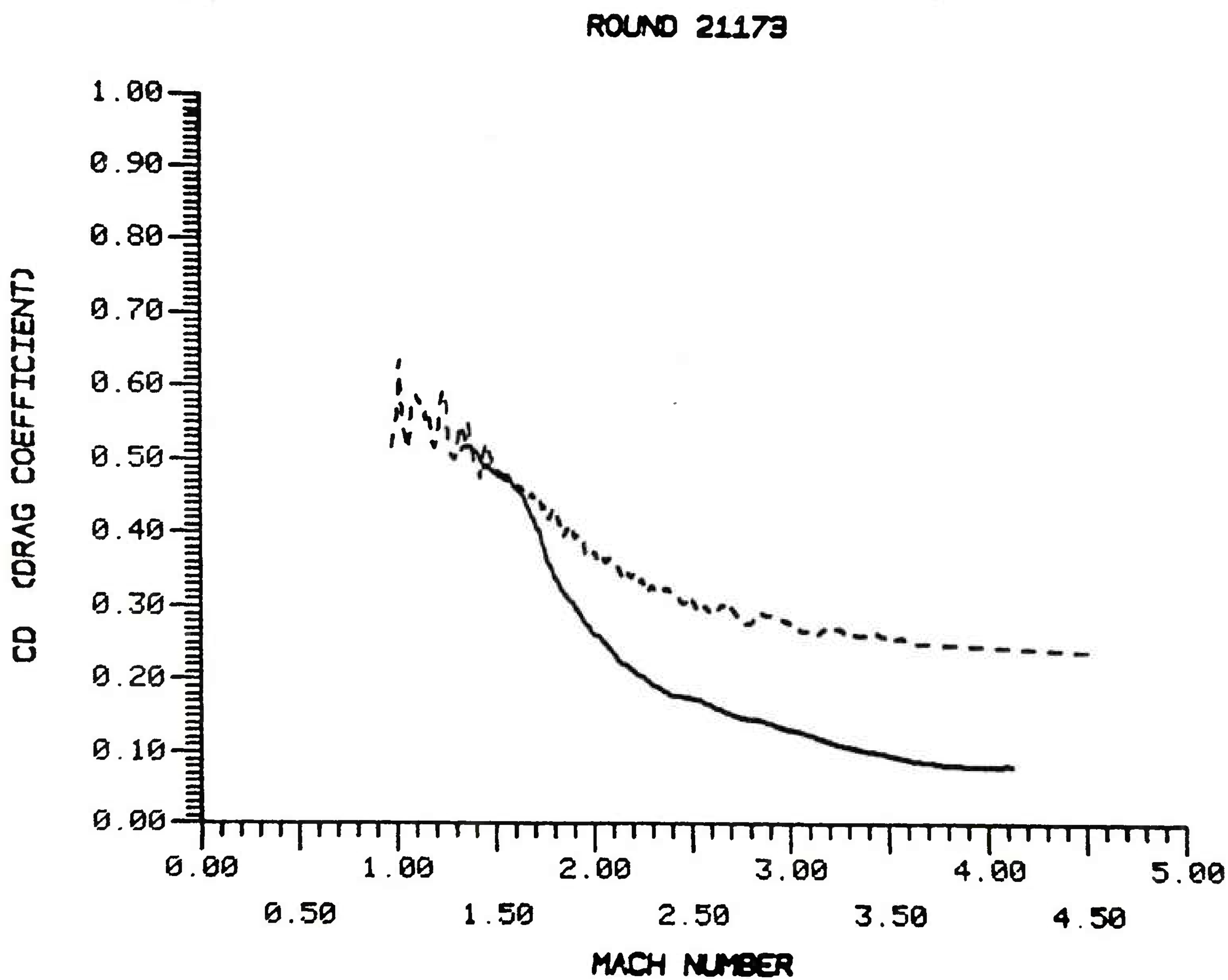

Figure 27. The Drag Coefficient C_D vs Mach Number (Round 21173).

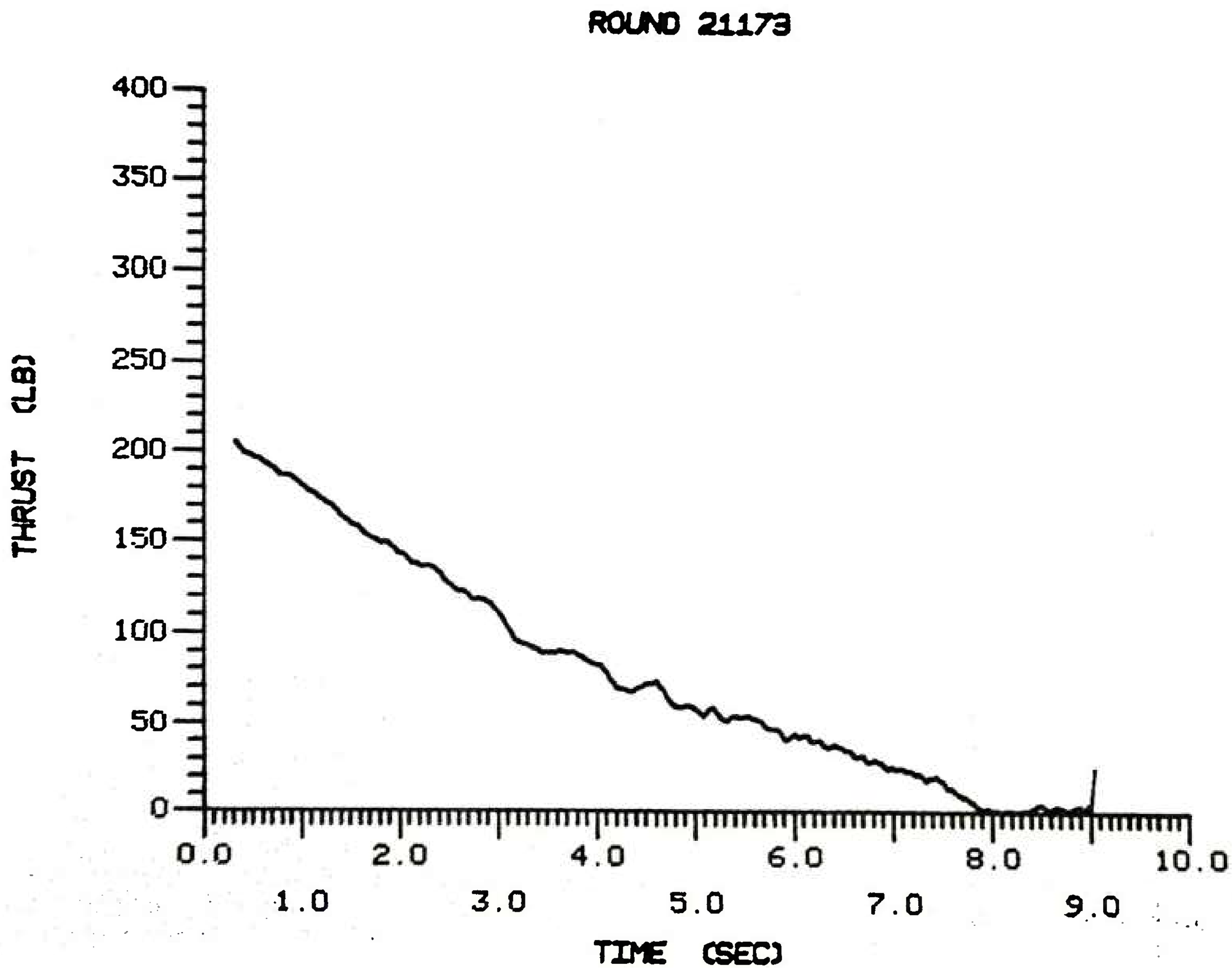

Figure 28. Thrust vs Time (Round 21173).

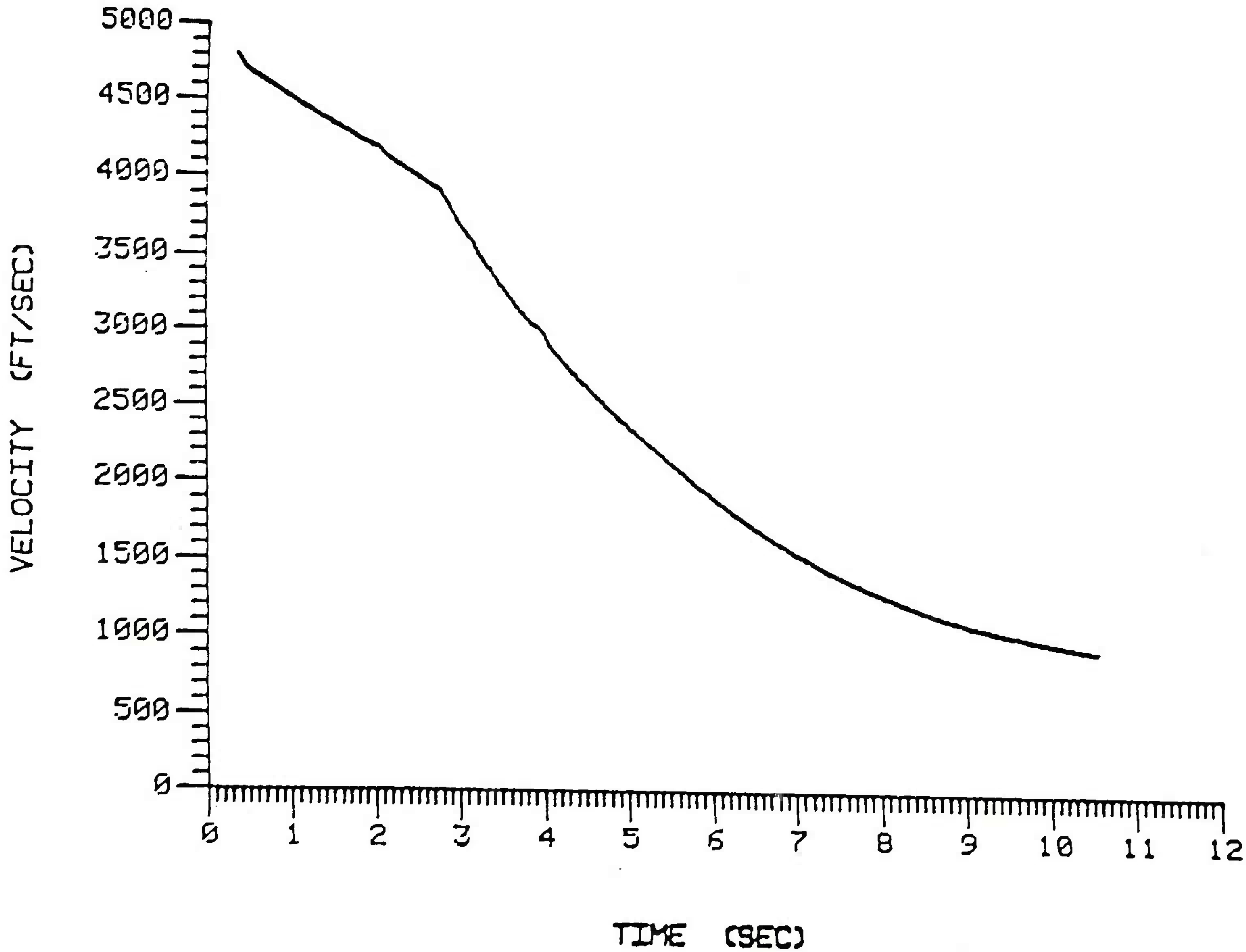

Figure 29. Velocity From Hawk vs Time (Round 21174).

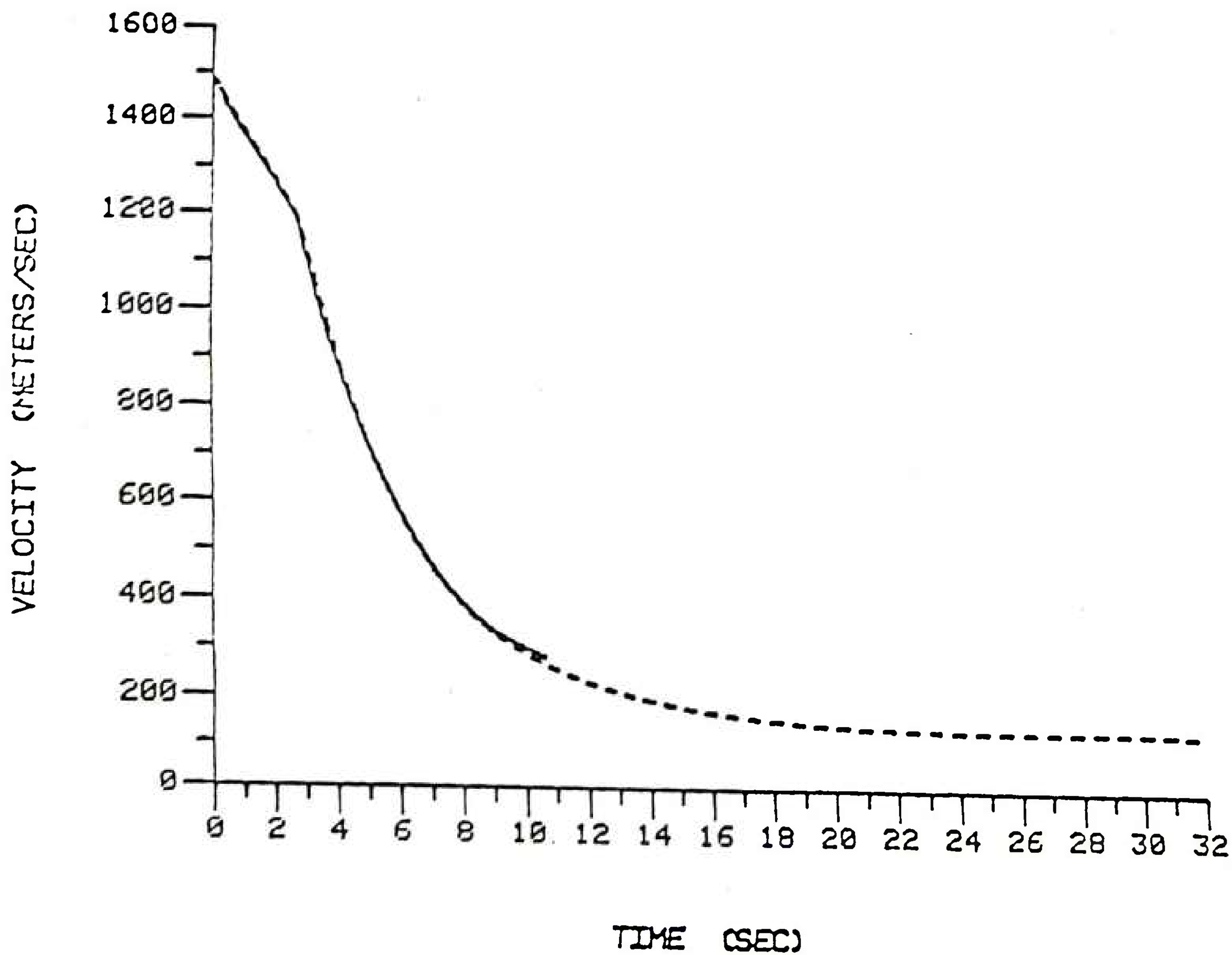

Figure 30. The Comparison of Velocities From Hawk and 6-DOF vs Time (Round 21174).

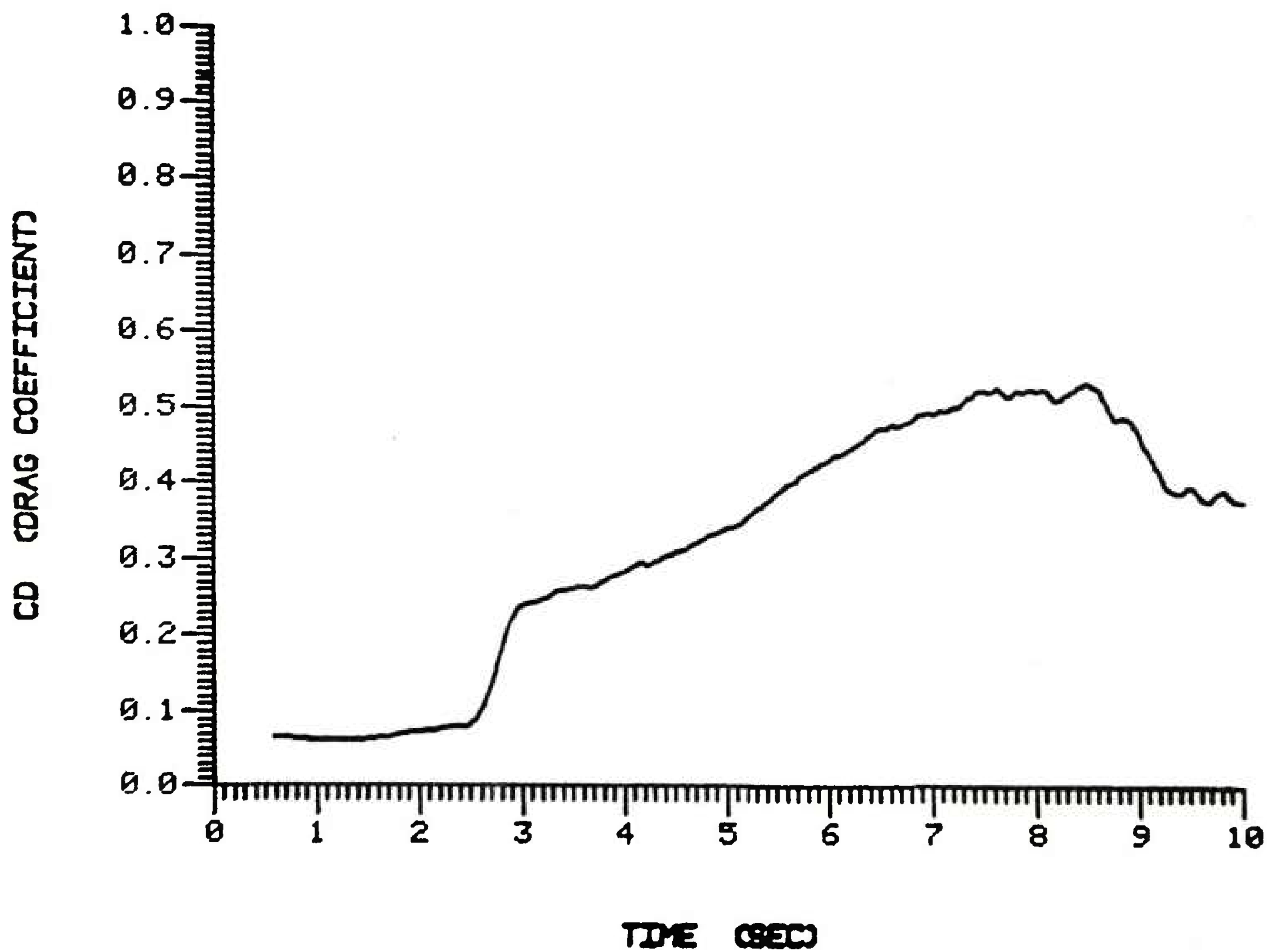

Figure 31. The Drag Coefficient C_D vs Time (Round 21174).

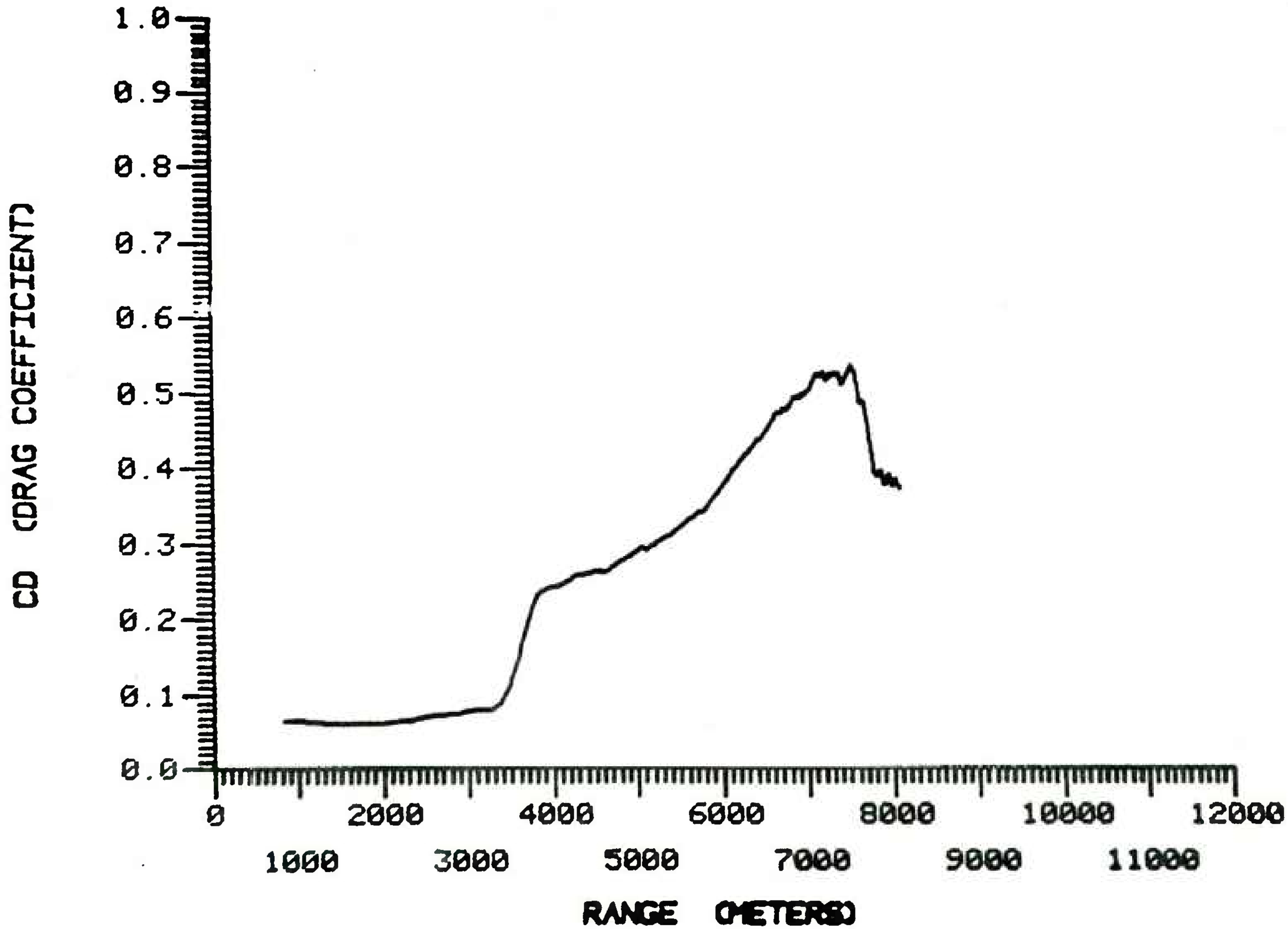

Figure 32. The Drag Coefficient C_D vs Range (Round 21174).

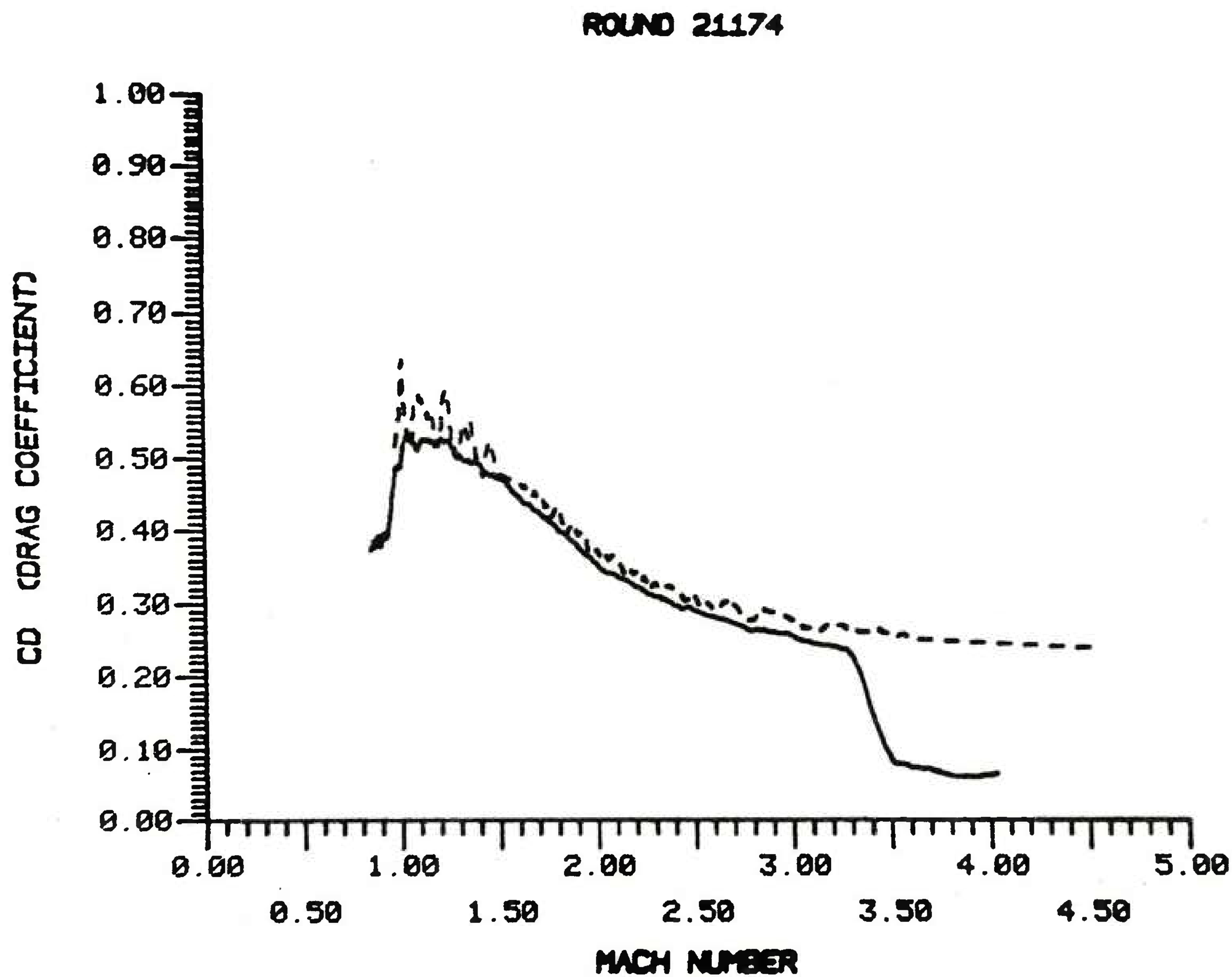

Figure 33. The Drag Coefficient C_D vs Mach Number (Round 21174).

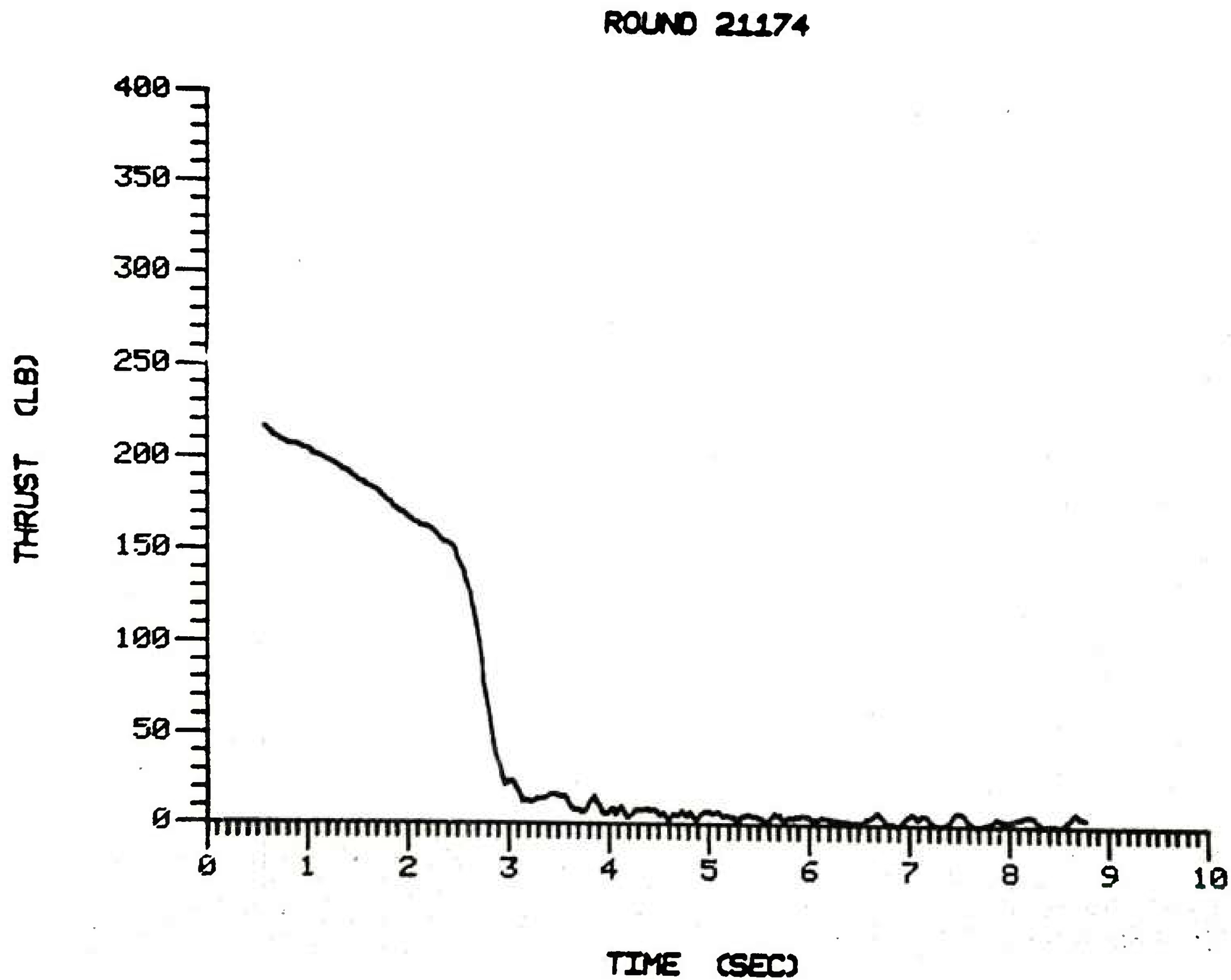

Figure 34. Thrust vs Time (Round 21174).

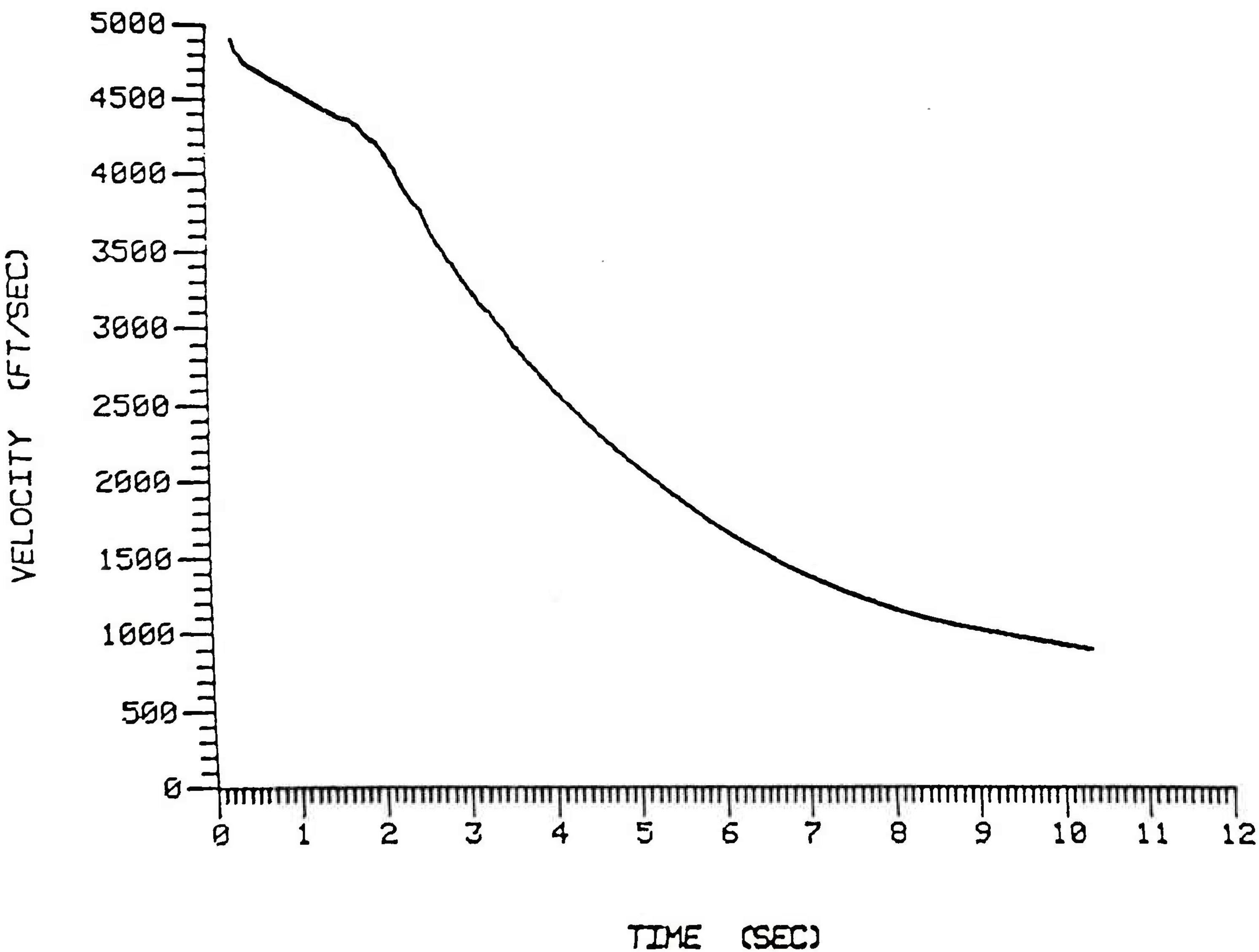

Figure 35. Velocity From Hawk vs Time (Round 21175).

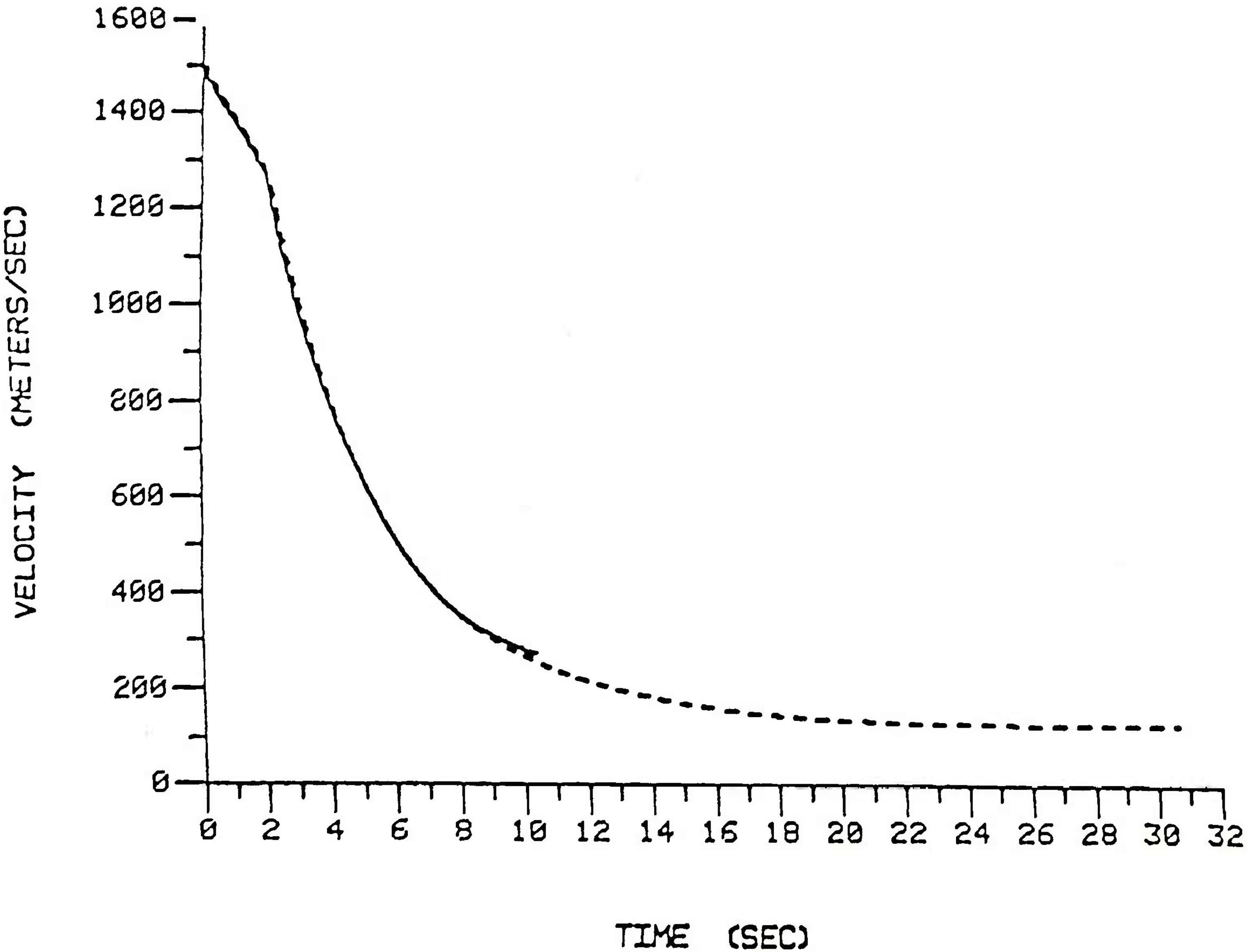

Figure 36. The Comparison of Velocities From Hawk and 6-DOF vs Time (Round 21175).

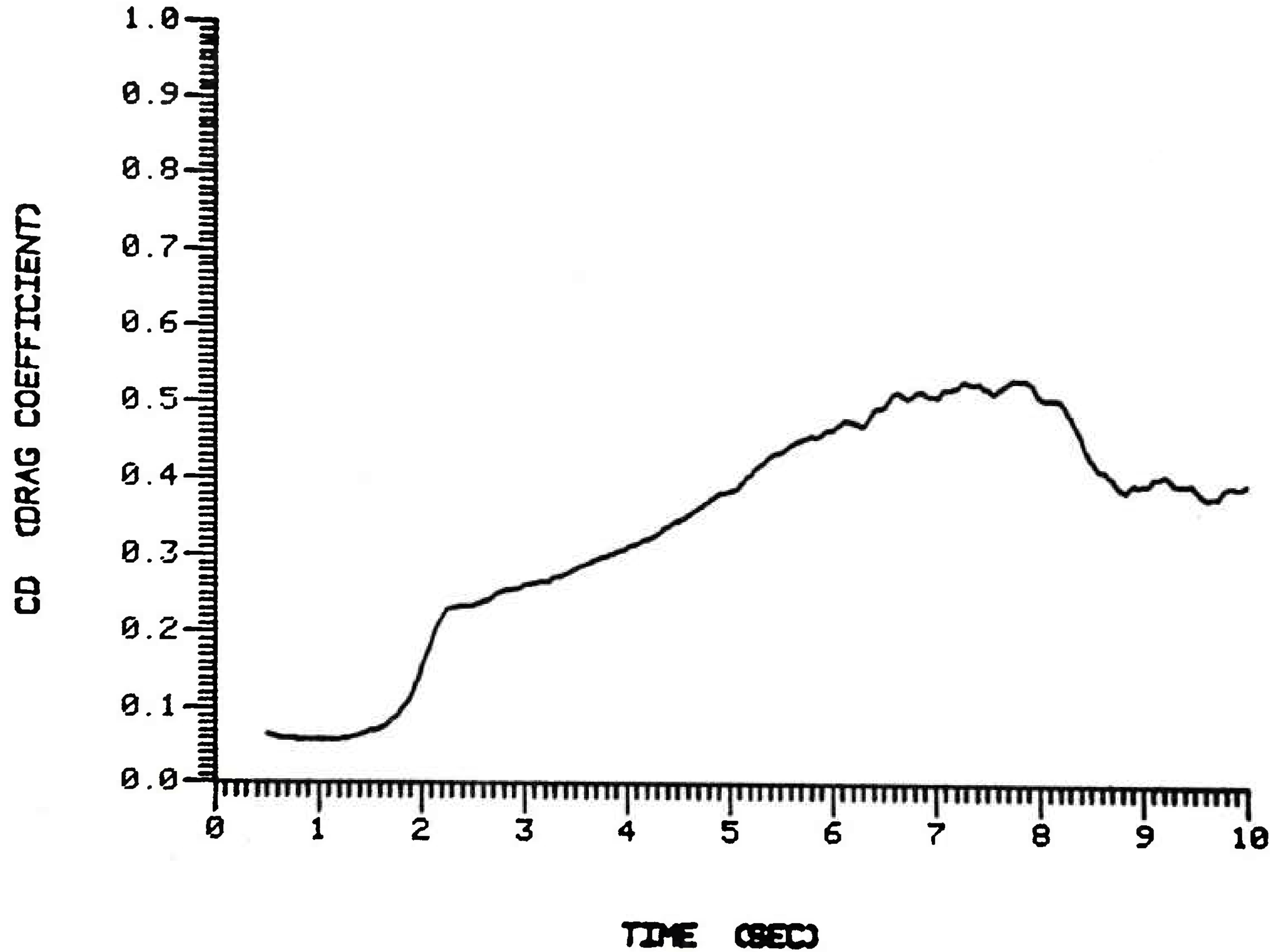

Figure 37. The Drag Coefficient C_D vs Time (Round 21175).

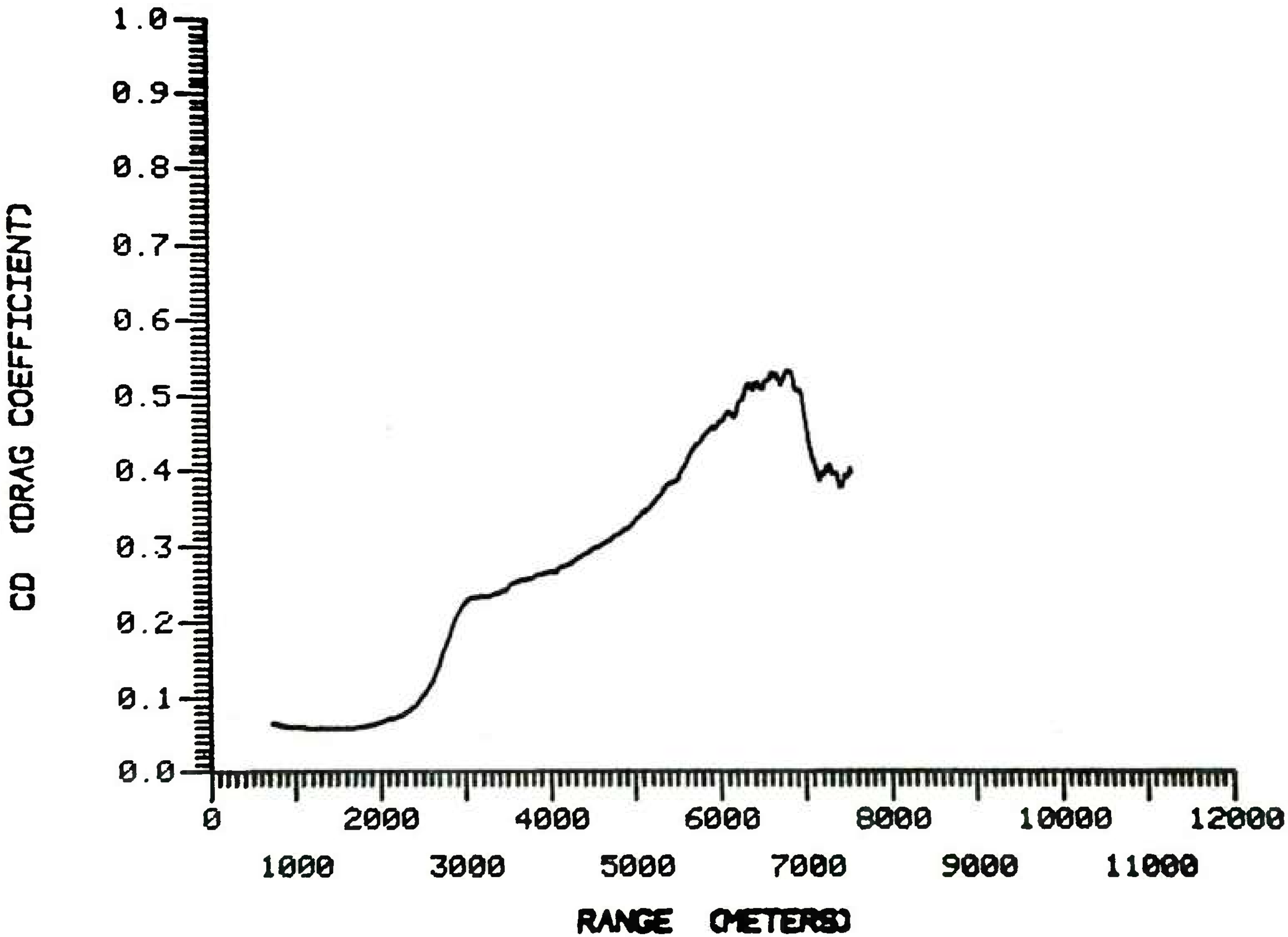

Figure 38. The Drag Coefficient C_D vs Range (Round 21175).

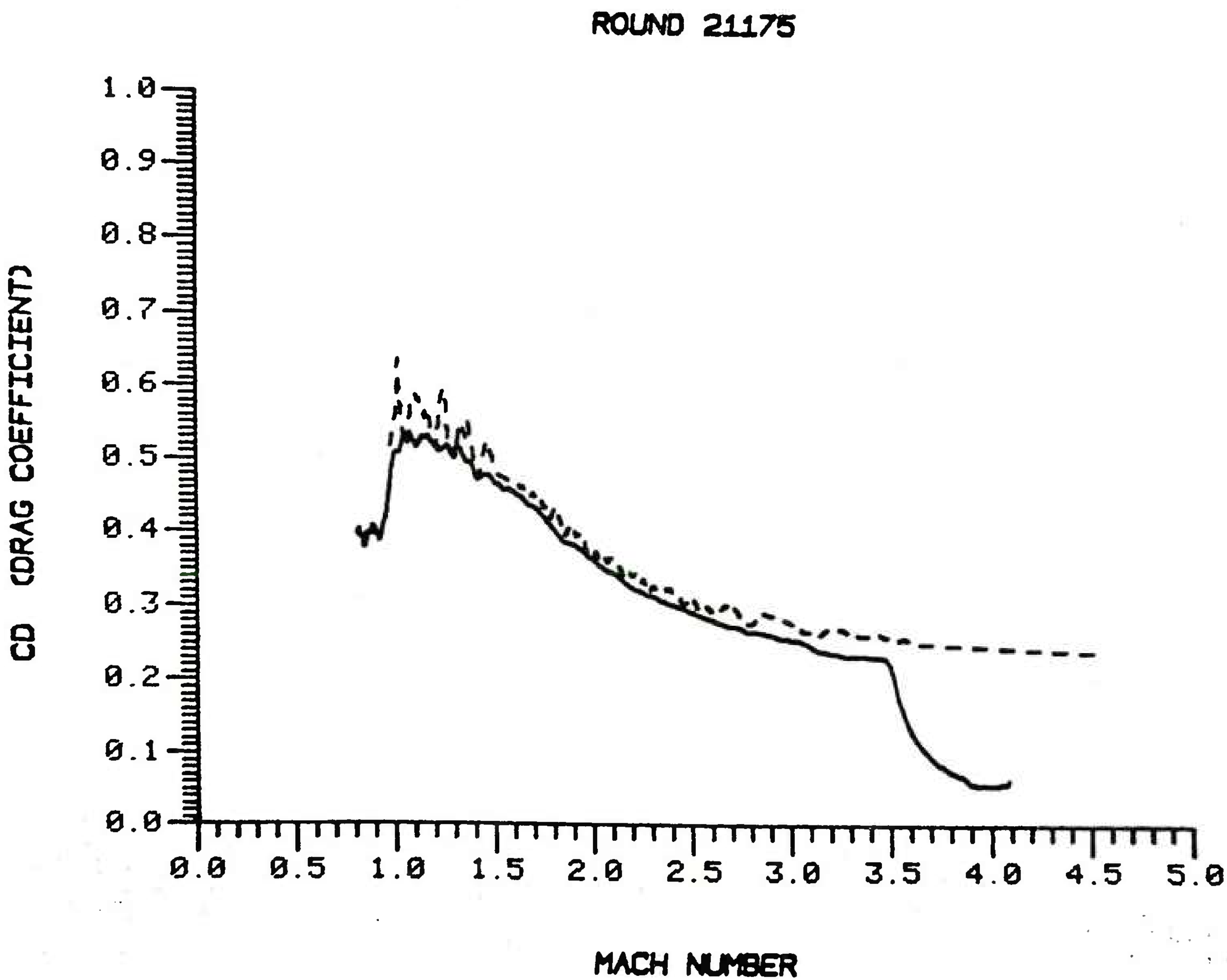

Figure 39. The Drag Coefficient C_D vs Mach Number (Round 21175).

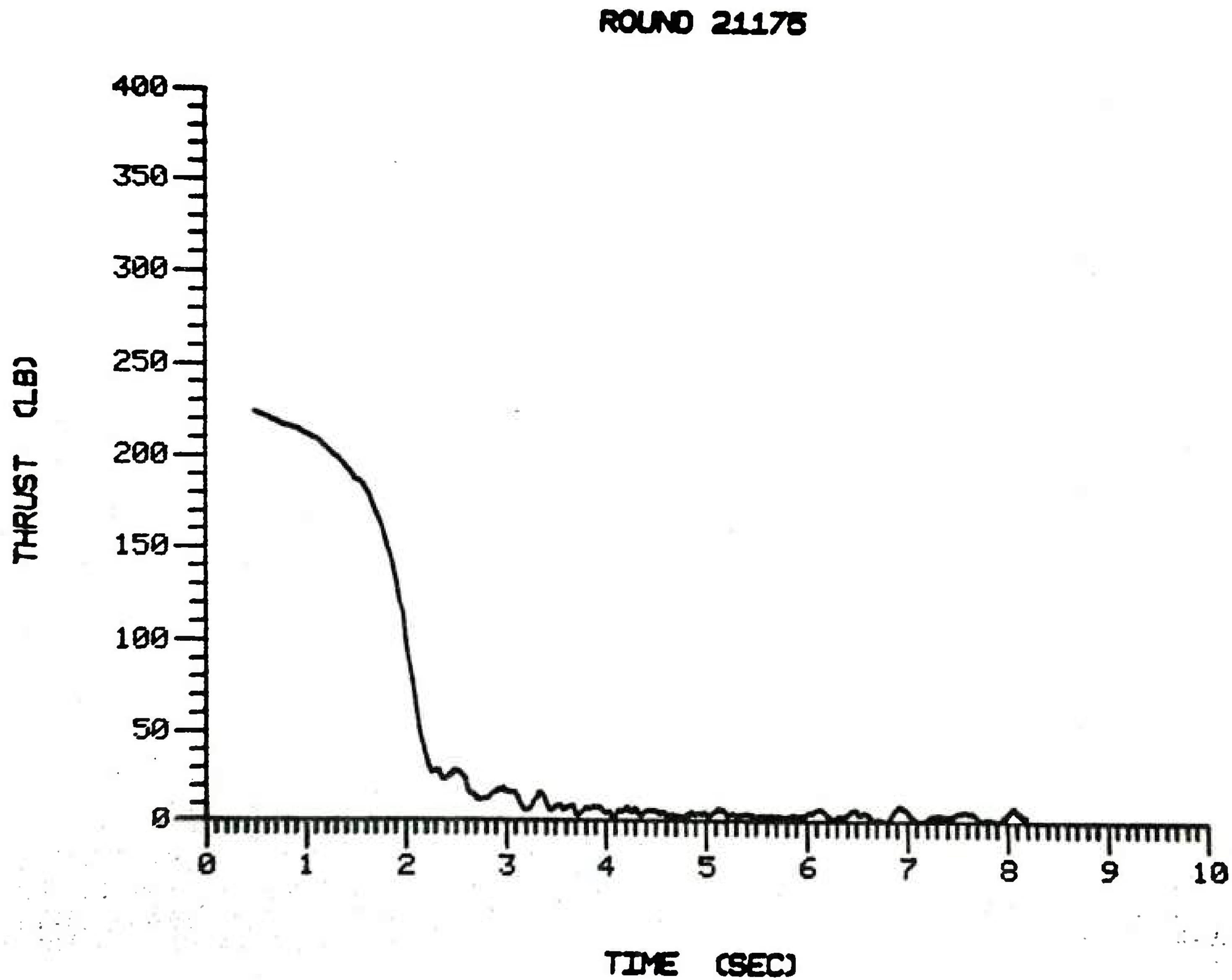

Figure 40. Thrust vs Time (Round 21175).

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